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ENGINE WEAR AND ENGINE LIFE

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by

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13. ABSTRACT

The author presents Russian research results from factories and State Institutes.

Micrometry, artificial incision, profilometry, and tracer methods of evaluating wear are all found to be useful, and plots are given.

Plots of oil consumption, gas blow-by, deformation, fuel consumption, effective power, and standard test rpm are among other techniques used in combination to evaluate engine condition.

Quality control and tolerances of parts, volume uniformity among cylinders, mixture distribution uniformity, and cleanness of piston grooves are cited as the crucial non-operational factors. Design factors -- notably cooling of cylinder sleeves and valve seats, choice of materials, stroke/diameter ratios, setting of oil passage angles in main bearings, piston design, exhaust gas flow patterns, cylinder and bearing alignment, and rod symmetry are discussed.

Break-in, maintenance, and overhaul strategies, and accelerated-wear testing methods for design and tolerance-setting purposes are outlined. Diamond abrasives are advocated in honing, to ensure moderate but controlled roughness.

With regard to engine operation, moderate rpm, avoidance of cold starts, and choice of fuels and lubricants with a view to maintaining integrity of the oil film without ring sticking or scale formation on valves are discussed.

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MECHANICAL TEST						
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CORROSION						
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NOTICE

Introduction

The importance of problems concerned with increasing the reliability and life of machinery is generally recognized in all branches of domestic machinery manufacturing.

The purpose of this book is to correlate and systematize the research material accumulated by the author in the area of wear and life of motor vehicle engines over 30 years of work at the Gorki Motor Vehicle Plant, and also information from the Zavolzhsk Engine Plant.

Some of the questions brought to light were published earlier in the monographs "Breaking-In of Motor Vehicle Engines," "Wear in Motor Vehicle Engines," and "Life of Motor Vehicle Engines," as well as in a number of pamphlets and articles appearing in collections and journals. In this work, these materials are updated with new investigations in the area studied and are also supplemented with a theoretically based set of experiments conducted previously, with the results obtained.

The present book, "Engine Wear and Engine Life," does not encompass the entire multitude of questions on this large and complex problem. The abundance of factors affecting reliability and life and the wide variety of existing types of engine models, differences in their conditions of use, statistical scatter in wear of parts and assemblies, and other reasons exclude the possibility of dealing with the status and evolution of the problem exhaustively in a single work. Beside this, due to the widespread introduction of the KANARSPI system, new resources for increasing durability and wear resistance in parts requiring theoretical bases arise daily, and new theories arise requiring experimental checking and testing under conditions of equipment operation. Numerous extremely valuable studies performed on samples in friction machines have still not been confirmed by tests of actual vehicles, and the results of complex studies on complicated assemblies contradict results obtained through analysis of the interaction of separate parts and units.

Therefore, in the problem of wear and life of machines, and particularly that of motor vehicle engines, the number of "blank spots" is still so great that many years will still be required to connect the disconnected links into a strong chain.

Special attention in the work has been given to methods for evaluating wear and to the characteristic features of its occurrence; to experimental and theoretical analyses of various design, engineering, and service factors affecting wear; and to the development of methods for accelerated testing of engines for engine life. The complexity of the relationship between the multitudinous factors affecting wear and life is aggravated to a significant degree by the large number of existing types and models of engines. Therefore, the author selected only a limited number of the more serious and least studied factors for analysis, and a comparatively small number of carbureted motor vehicle engines as the object of investigation. For subsequent correlation, the experiments were conducted on models which differed in the number and arrangement of cylinders, system of gas distribution, materials of certain parts, and other features. To obtain objective data, the experimental methodology was based on initial experiments on small lots of engines of a single model, with subsequent tests on large lots. This sort of multistage investigation scheme is a logical continuation of a large number of tests performed on models and friction machines.

The book is intended for designers, technicians and researchers in machinery manufacturing and motor vehicle plants, engineers in motor vehicle repair enterprises and motor vehicle transport establishments, and also workers in the Scientific Research Institutes and Institutions of Higher Learning who are interested in the questions of reliability and life of machines.

The author extends sincere recognition to his co-workers at the Central Scientific Research Laboratory of Engines at the Gorki Motor Vehicle Plant, with whose help this and preceding work in the area of engine wear and engine life came about, and thanks in advance those writers who, disagreeing with the work, send their responses concerning the book to the address of the publisher.

Chapter I

The State of the Problem of Engine Wear and Engine Life

Increasing Engine Quality Stability

Guaranteeing long life in vehicles, and in particular in motor vehicle engines, requires comprehensive analysis of the causes and conditions leading to increased or premature wear in parts.

These causes can be broken down into three basic categories: design, engineering, and use. Their effects on wear and life sometimes appear separately, but significantly more often they are combined.

In actuality, isolated design decisions without consideration for the engineering possibilities of manufacturing the parts can to a significant degree contribute to a decrease in wear resistance. If during design such parameters of the unit or component as convenience of preventive maintenance and repairability are not considered to the required degree, the total service life yielded by them turns out to be significantly shorter than that possible. In a case where the manufacturing plant procedure does not provide for the required running-in of vehicle parts friction surfaces, the unavoidable extension of this process into the initial use situation can cause premature wear in fitted assemblies. There are an endless number of similar examples testifying to the necessity of simultaneously considering the effect of design, engineering, and use factors in creating new machinery, including engines.

The above statements characterize one of the essential methods for increasing engine life and overall engine quality. Another, no less essential factor governing product quality to a significant degree is the instability of parts characteristics, beginning with the stock and ending with the final operations of machining, assembly of subunits, and engine break-in.

Instability of stock quality can appear, for instance, during redistribution of internal stresses in the metal in the process of machining parts and even during assembly of subunits and the engine as a whole.

Instability of quality also appears with excessively large assigned tolerances of part dimensions and friction surface roughness, and even more with violation of such assigned parameters under production conditions. In some cases, experience points to the necessity of reducing these tolerances to increase life and other characteristics of engine quality. It has been established, for instance, that the average initial deviation from nominal values of maximum effective horsepower for the GAZ[1] -69 and UAZ[2] -450 engines averages 6%; for GAZ-51 engines, up to 9%; for GAZ-21 engines, nearly 8%, etc. One of the main reasons for such a significant spread in power indices of new engines is the extremely large range of tolerances for combustion chamber volume, and the difference in cylinder volumes in a single engine. Thus, a difference in combustion chamber volumes of up to 3 cm^3 is allowed in GAZ-59 and GAZ-51 engines, and up to 2 cm^3 in GAZ-21 engines, giving a compression ratio variability on the order of 0.2:1. The correlated results of tests on more than 20 engines with accuracy sufficient for practical purposes have established that even this small a variation in compression ratio can lead to a decrease or increase in power of 2 - 3.5% and a change in speed-dependent fuel consumption of 2 - 5.3%.

In addition, nonuniformity in combustion chamber volume causes some variation in gasoline octane number required. This makes it advisable to decrease tolerances for the volumes and differences in volumes of combustion chambers, by machining them.

A no less essential factor affecting stability of power and fuel consumption is the presence of resistance to the gasoline-air mixture intake. Resistance primarily arises as the result of covering of the intake ports in engine blocks as a result of gasket or intake manifold shifting. Formerly, under engine production conditions at the Gorki Motor Vehicle Plant, covering of the intake ports reached a value of 2 - 3 mm, which decreased the passage area up to 8.5%. It was established by the results of a special test that covering of the intake ports by this amount reduces the maximum speed-dependent effective power by an average of 1.5 - 2% and increases minimum specific fuel consumption by 2%. On the basis of these results, measures were introduced at the Gorki Motor Vehicle Plant to eliminate the covering of intake ports in engine blocks.

Along with this, an increase in resistance to gasoline-air mixture intake is also promoted by projections and unevenness of foundry origin on the inner surface of the intake manifold. Studies of GAZ-21 engines showed that smoothing the intake manifold by preliminary sand blasting provided an increase in engine power of 2 - 3% and a reduction in specific fuel consumption of 5 - 7%. There has not, however, been sufficient attention directed toward this problem up to the present time.

Factors regarded as determining instability in power and economy indices also include unevenness of mixture distribution among the cylinders, the presence of liquid-state fuel beyond the carburetor, dissimilar angles of

1 GAZ is a trademark of the Gorki Motor Vehicle Plant

2 UAZ is a trademark of the Ul'yanovsk Motor Vehicle Plant

ignition advance, unevenness in cylinder cooling conditions, differences in the level of friction loss in the cylinders, and many others.

Similar relations expressing the effect of initial parameters on subsequent instability of engine quality appear to an even greater degree in relation to engine life. Frequent cases of premature intensive wear in one of the cylinders of an engine with normal operational wear in the neighboring cylinders are evidence of such a relation.

Cases of failure in separate crankshaft pins, or one or two valve stems, etc., while friction surfaces of other parts of the same type are fully operational are well known.

Finally, certain lots of production engines are operated without major overhaul for a duration of 120000 - 150000 vehicle km, while for other engines of the same model in fairly similar operating conditions, overhaul after 60000 - 80000 vehicle km is required.

A significant spread in the amount of parts wear takes place even during the conduct of engine test stand tests under identical conditions, where the spread is governed only by the effect of design and engineering factors.

Fig. 1 shows the distribution of parts wear as the result of 100-hr test stand tests according to plant TU [Engineering Specifications] of 60 GAZ and ZMZ engines, of which 30 were model GAZ-51 engines, 15 were model UAZ-69 and UAZ-450 engines, and 15 were GAZ-21 engines.

A somewhat narrower distribution accompanies higher absolute values of wear, as seen in the results of 400-hr test stand tests of GAZ and ZMZ engines according to GOST [All-Union State Standard] 491-55, which are presented in Fig. 2.

The distribution of cylinder wear as a result of extended operation of engines in motor vehicles, regardless of the greater absolute value of wear, is broader than the distribution during test stand tests because of the additional effects of a large number of operating factors. Thus, according to statistical data, normal scatter in maximum cylinder wear in various engines during service in motor vehicles reaches ratios of 1 : 3, and in a single engine is within limits of 1 : 1.2 to 1: 1.8. It has been established that the distribution of service lives of GAZ-21 engines before major overhaul lies within limits of 1 : 1.8 to 1 : 2.2, and that of engines having undergone major overhaul reaches 1 : 3.64. The unevenness of wear in tractor engines is no less significant. According to data of the Odessa Research Station of NATI [State All-Union Scientific Research Institute of Tractors] in 1950, the amounts of maximum cylinder sleeve wear varied over limits of 1:1.2 to 1:1.8.

Results of statistical treatment of parts wear measurements in GAZ and ZMZ engines after extended operation of motor vehicles which confirm and supplement these data are presented in Fig. 3.

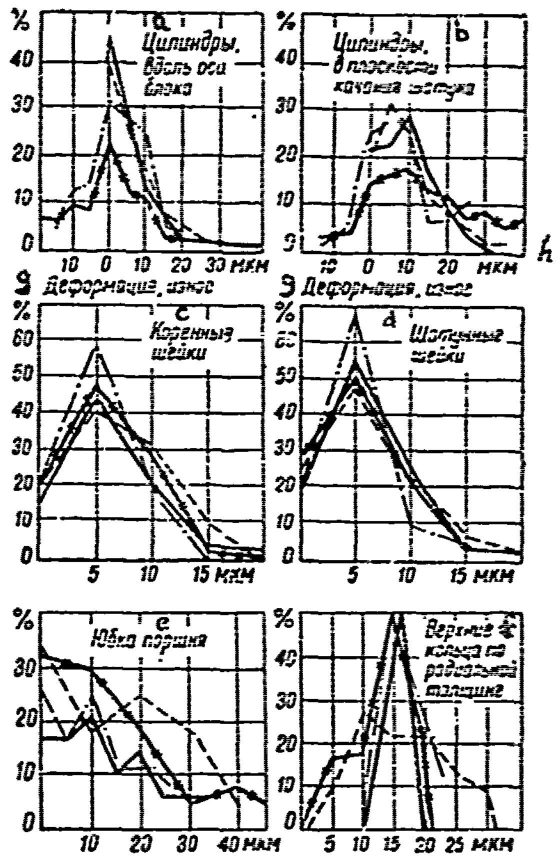

Fig. 1. Distribution of Parts Wear after 100-hr Test Stand Tests of Engines According to Plant TU:

—— GAZ-51, ---- UAZ-450, XXXX GAZ-21, -·-· GAZ-53

Key: a) cylinders, along block axis; b) cylinders, in swing plane of connecting rod; c) main journals; d) connecting rod journals; e) piston skirt; f) radial thickness of upper rings; g) deformation, wear, μ

A large number of design and engineering factors also affect the distribution of wear in like parts and the spread of power and economy performance of engines. These might include, for example, extremely wide tolerances in initial micro- and macrogeometries of parts which were set in the design and aggravated by sources of block deformation during manufacturing of 6-cylinder flathead GAZ engines, and by sources of cylinder sleeve deformation in ZMZ engines; imperfections in piston ring manufacturing technology, in which nonclearance fit against the working surfaces of cylinders is not assured; process irregularities in the piston ring porous chroming process, as a result of which the pore number density and the depth of the porous chrome layer are highly unstable; and a number of other factors.

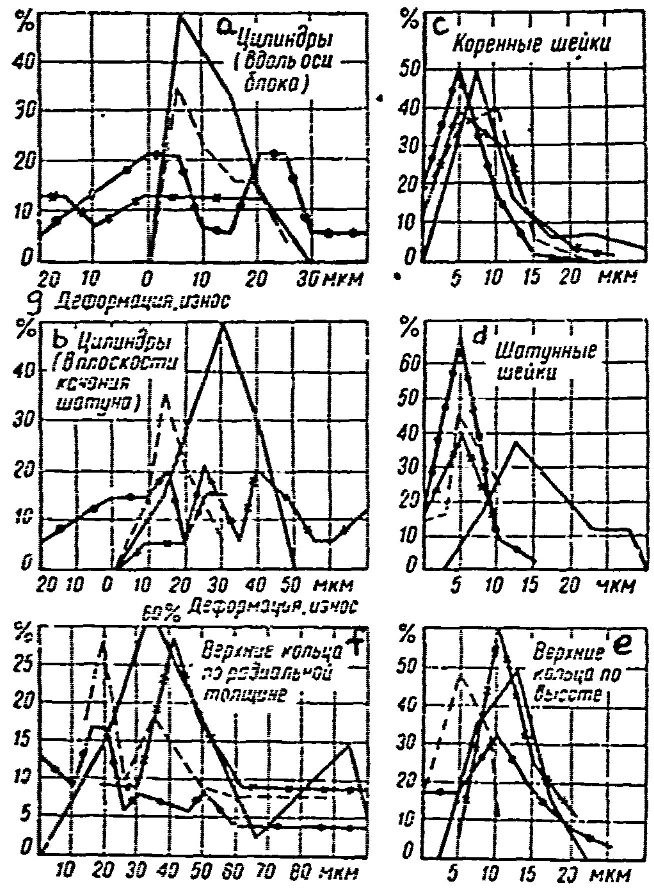

Fig. 2. Distribution of Parts Wear after 400- and 600-hr Test Stand Tests of Engines According to GOST 491-55:
—— GAZ-51, ---- UAZ-450, XXXX GAZ-21, -•-• GAZ-53

Key: a) cylinders, along block axis; b) cylinders, in swing plane of connecting rods; c) main journals; d) connecting rod journals; e) height of upper rings; f) radial thickness of upper rings; g) deformation due to wear, μ

For illustration, Fig. 4 contains distribution graphs of initial microgeometries of parts going into assembly of GAZ and ZMZ engines, and Fig. 5 shows the distribution of geometric parameters of some parts upon completion of final machining and heat treatment processes.

All these and similar examples are criteria for the state of the art in production, and designers and technicians must begin from these original data when working on engine quality. Underevaluation of the key role of these initial parameters, lack of thorough study of their effect on subsequent

performance capability of parts, the absence of proper organization of research work, and the lack of scientific foundations behind the necessity of introducing certain measures into production in order to solve this problem are basic reasons for the insufficiently high quality of engines produced.

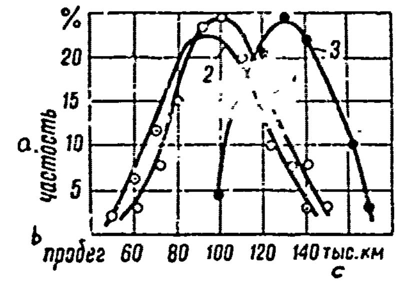

Fig. 3. Distribution of Engine Life During Operation of Motor Vehicles in the Central Region of the USSR
1. GAZ-51; 2. GAZ-M20; 3. GAZ-21

Key: a) frequency; b) service life; c) thousand km

Underevaluation by managers of enterprises performing investigative and research tasks and misunderstanding of the guiding role of plant laboratories in determining the quality of products have arisen in many cases. Beside this, objective criteria and methods for evaluating product quality are often lacking.

In recent years, important advances have been made in this direction, assisted in many respects by the KANARSPI system. The name of this system is an acronym of the slogan: "Quality, reliability, and engine life from the first products." The system is a set of scientific, engineering, and organizational measures encompassing the stages of planning, production, and operation of products and ensuring their high quality beginning with the first industrial prototypes.

The basic characteristic features of this system include the early design and engineering development of the products, all possible eventualities of scientific research directed toward increasing their reliability, coordination of tasks and creative collaboration of the fundamental plant laboratory work with scientific research institutes, the development of control and research laboratories, the devising of objective methods for evaluating quality of products, development of methodologies for accelerated test stand testing for life of certain subunits and products as a whole, and perfection of methodologies for service life testing.

These and a number of other features of the KANARSPI system are guarantees of high product quality. A characteristic example of the use of the KANARSPI system in engine production at the Gorki Motor Vehicle Plant is the systematic laboratory quality control in parts manufacturing, and, on the basis of this control, the organization of research into the possibility of

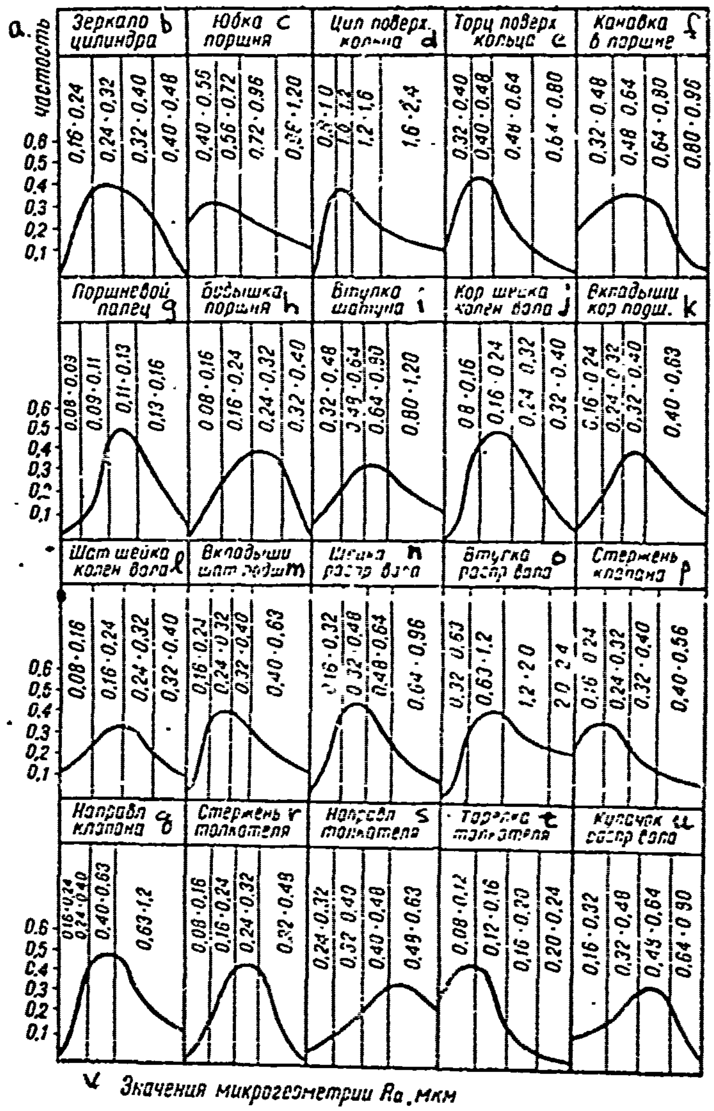

Fig. 4. Distribution of Initial Microgeometries of Parts for GAZ and ZMZ Engine Production

Key: a) frequency b) cylinder wall c) piston skirt d) inside face of ring e) outside face of ring f) piston groove g) wrist pin h) piston boss i) rod bushing j) crankshaft main journal k) main bearing insert l) crankshaft connecting rod journal m) connecting rod bearing insert n) camshaft journal o) camshaft bushing p) valve stem q) valve guide r) tappet rod s) tappet guide t) tappet plate u) cam v) microgeometry index Ra, microns

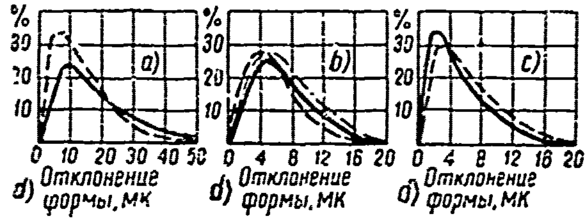

Fig. 5. Distribution of Initial Errors in the Shapes of parts, in the Production of GAZ and ZMZ Engines:

a) cylinder walls b) crankshaft journals c) camshaft main journals
d) deviation in shape, microns
—— ovality, ---- conicity, -·-· degree of saddle shape

increasing engine quality. Thus, in the process of extended observation of final machining operations on crankshaft main and connecting rod journals by means of multiple measurements of shape error, the distribution of this parameter was found and is presented in Fig. 5.

These diagrams show that most of the journals are manufactured with a deviation from the cylindrical shape of up to 0.006 mm, with a tolerance for this parameter, set by GOST 4669-54, of 0.01 mm. However, a significant number of journals have been manufactured at the upper limit of noncircular cross-section.

Meanwhile, in the manufacture of crankshaft journals, sharp "pressures" along the edges of the working surfaces of the bearing inserts were observed at the upper limit of this tolerance, as a result of which premature chipping of the working coating was promoted. Special tests established that the optimum tolerance for ovality, conicity, and concavity of journals with respect to running-in of fit should be maintained within 0.006 mm. With this, the service life of the fitted assembly increases by 50 to 80% and, in addition, the journal wear rate is more stable.

A typical example of a combined design and engineering solution to the problem of increasing engine life in GAZ-51 engines and their modifications is the modernization of the crankshaft in these engines by changing the directions of oil passages. On the basis of numerous investigations conducted under the direction of A. A. Kuz'min, it was established that the many cases of premature wear in the second and fifth connecting rod journals which occurred under operational conditions of these engines were the result of insufficient lubrication due to the incorrect choice of oil passage angle of inclination.

Design changes made on the basis of these investigations, and assimilation of the modified crankshaft into the production scheme totally eliminated premature wear in the second and fifth connecting rod journals.

Such combined work of researchers, designers, and technicians on decreasing deformation of cylinders in certain models of flathead 6-cylinder GAZ engines is typical of the KANARSPI system. The deformations up to 0.05 - 0.06 mm which occurred earlier in new engines, with a tolerance for out-of-round cylinder shape of 0.025 mm, were reduced by more than 30% by introducing artificial aging of the stock in the production process.

Also, this work was preceded by research on causes of cylinder deformation, which revealed the redistribution of residual internal stresses in stock during machining and even engine assembly.

A combined design-engineering solution was also found in the area of controlling the pore number density and depth of the porous layer on chromed compression piston rings (this improved running-in and reduced the probability of the appearance of cylinder scoring); also, in the area of preventing tappet head scoring by means of the introduction of hot parkerizing; and in the area of improving the running-in of engine parts by using DF-11 additive to the break-in oil, etc.

The KANARSPI system also was a stimulus for developing objective methods for evaluating the technical condition of engines according to a set of parameters -- oil burning and gas leakage; the evaluation of engine break-in according to the reduction in mechanical power loss and stabilization of the rate of crankshaft revolution in the presence of a metering plate; and evaluation of the effectiveness of measures directed toward increasing engine life, by developing methodology for accelerated testing. All these and a number of other questions touching on the problem of increasing motor vehicle engine life are illuminated in the following chapters of this work.

In conclusion, it should be noted that the KANARSPI system, introduced in a number of enterprises in the city of Gorki and its surrounding area, has fully justified itself. Due to this system, the service life before major overhaul of "Volga" automobiles was increased from 120,000 to 200,000 km, and the life of GAZ engines was increased from 120,000 to 160,000 vehicle km at the Gorki Motor Vehicle Plant.

The "Dvigatel' Revolyutsii" ["Engine of the Revolution"] Plant increased the engine life of 6436/45 diesels by 50%, increased that of 423/1 diesels from 15,000 to 20,000 hr, and increased that of 10GK gasoline motor compressors from 30,000 to 50,000 hr. The KANARSPI system has had no less an effect upon introduction at the "Krasnoye Sormovo" Plant, at the Gorki Television Plant imeni Lenin, and at other enterprises.

Terminology and Classification of Wear in Motor Vehicle Engines

A review of terminology facilitating the interpretation of various phenomena, parameters and values usually precedes the establishment of classifications and the analysis of criteria of understanding of a problem. It should not be supposed that terminology will solve or decide the outcome of the problem to any significant degree. However, different interpretations of terminology and definitions sometimes lead to confusion when they are used, thereby complicating solution of certain problems. Terminology in the area

of reliability and product life is developed to a much greater degree in the radio electronic industry.

The results of this work were made the basis of State Standard 13377-67, "Engineering Reliability," which established the basic concepts and terms in the area of product reliability.

In accordance with this standard, the most common concepts characterizing machine quality, and in particular engine quality, are performance capability and reliability. Performance capability specifies the state of an engine at which it can perform given functions with parameters established by the requirements of the technical documentation.

Performance capability is signified by operating indices and limits of their change allowable in operation. It is governed by wear resistance and durability in parts and subassemblies of the engine, the stability of adjustments and heat conditions, etc., as well as by zero-defect design, engineering, and manufacture. Reliability is understood to mean the property of the engine to perform given functions while maintaining its operational indices within established limits over a required time period or required running time period. Reliability of any product, and in particular of a motor vehicle engine, is characterized by freedom from failure, repairability, preservability, and long life. Therefore, long life is an element of the more general concept of reliability and manifests the ability of the engine to maintain its performance capability up to the terminal state, with necessary interruptions for technical service and repairs.

The terminal state is in turn characterized by the limiting values of wear, clearances, power, fuel consumption, oil burning, and blow-by of gases. It is determined in general by either a limiting decrease in efficiency or by safety requirements, and often by economic expediency. In this case, the question is that of optimum engine life. The most important index of life is useful life or so-called running time of the engine up to the terminal state, which is specified in the technical documentation. This index is called the "reserve", or when the discussion is based on the calendar duration of operation, the service life of the engine. The "reserve" before first overhaul, between-overhaul "reserve", average "reserve", intended "reserve", gamma-% "reserve" and so forth are different, and for special conditions of stand or road testing there may be a specially defined "reserve". The basic statistical indices of the life of machine elements in this concept are the average "reserve", which characterizes the running life of a product up to its terminal state, and the gamma-% "reserve"[3], which represents the life of a selected percentage (gamma %) of the products.

The task of machine manufacturing in the area of increasing the life time boils down to the necessity for increasing the average running life of the product, i.e., increasing the level of the running life and gamma-% running life, which increases the running time before early failures and reduces the number of same. A reduction of the scatter in the running lives is also needed, along with better matching of the average running lives of the more

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[3] [Translator's note: Hereinafter, the narrowly-defined word "reserve" will be translated "running life".]

critical parts, subassemblies, and assemblies of the machines. Study of questions of long life in products, including motor vehicle engines, is primarily based on research into parts wear and on development of methods for reducing it.

This area of knowledge dealing with lifetimes contains a whole range of special terms and definitions which are not present in GOST 13377-67. The majority of them are commonly known, but many authors assign different meanings to them. In connection with this, Table 1 presents the most important terms and definitions used in the following chapters of this work. The terms and definitions presented in Table 1, for example, initial, operational, premature, and terminal wear of parts, and also wear and tear, rate of wear and tear, and others, depend on the effect of many factors, which can be broken down into three main categories: design, engineering, and use factors.

These factors in essence define the magnitude and character of wear, whose classification promotes the development of measures increasing the life time of motor vehicle engines.

Such a classification can be subdivided with respect to periods and types of wear. It has been accepted in the literature to consider three periods of wear: initial wear or running-in; settled wear, corresponding to the period of normal operation; and catastrophic wear, characterizing rapid loss of performance capability.

Table 1

Term	Definition and Characteristic
Initial wear or running-in of parts	Change in parts condition, as a result of which the preparation of the engine to absorb operational loads is effected. This is achieved by using assigned methods and conditions for breaking the engine in.
Running-in capability of parts	The capacity of engine parts to be run in without the appearance of scoring, seizing, deformations, and other phenomena which cause defects, failure, and premature wear.
Operational wear of parts	The result of the destruction process of a part's surface caused by mechanical & heat loads, corrosion, and other factors; accompanied by a loss of weight, usually a distortion in shape, and sometimes by a change in the condition of metal surface coatings
Wear and tear on parts	The process of constant change in parts parameters with a loss of weight and usually with distortion in shape. It is brought on by the effect of causes listed in the definition of the preceding term.

Table 1, cont.

Term	Definition and Characteristic
Rate of wear and tear on parts	The increase in wear per unit time. When expressing the duration of service by the service life of a motor vehicle, the term "wear and tear intensity" is used. The instantaneous rate of wear and tear is equal to the first derivative of the wear with respect to time.
Premature parts wear	The result of the destruction process of parts surfaces during the running-in or initial operating periods, characterized by a weight loss of a degree normally associated with older engines. It usually arises as a result of seizing and scoring of the friction surfaces, extreme deformation, and other similar causes.
Terminal parts wear	The maximum value of wear of parts or clearances in their fits, above which the further operation of the engine is impossible or inadvisable. It is also characterized indirectly by a limiting rise in oil burning, etc.
Wear resistance of parts	The capacity of a part to resist wear and tear under defined conditions and within set limits. It is characterized by properties of the material, the design of the part, and the technology of its manufacture.
Durability of parts	The capacity of parts to resist all types of destruction or changes in form under the effect of loads and environments under set conditions and within set limits. High durability ensures engine operation without breakdown and without harmful results of wear, corrosion, etc.
Endurance of parts	Capacity of engine parts to resist destruction under the effect of multiple repetitive loading. "Fatigue strength" of parts is a synonymous term.
Deformation of parts	The process of changing the parameters and shape of a part without a loss in the weight, caused by the action of mechanical and heat loads. It is determined by properties of the part, and by techniques and conditions of the engine's use.

Research in recent years, including research by the author of this work, forms a basis for more detailed and clear demarcation of the periods of wear

in motor vehicle engines.

In particular, it is expedient to classify the first stage of wear as the period of full running-in, after which the micro- and macrogeometric running-in of the parts' friction surfaces are effected, and the indices of mechanical power loss and effective power, as well as such parameters as specific fuel consumption, oil burning, and blow-by of gases through the piston rings are relatively stabilized. Upon the completion of full running-in, the engine can be considered ready to accept operational loads. The duration of this period is on the average 60 - 80 hours of engine stand testing under loads according to the conditions of GOST 491-55, which corresponds to 2500 - 3500 km of vehicle service. For the majority of modern motor vehicle engines, full break-in corresponds in time to approximately 1.5% to 2.5% of the total period of operation before major overhaul. According to the proposed classification, full break-in is divided into initial and concluding periods. The initial period occupies a time period of from 20 min to 3 - 5 hr, depending on conditions and methods of the engine break-in and also on the engineering sophistication of the production process and size of the motor vehicle enterprise. The preliminary cutting, evening, and smoothing of roughnesses on the contacting macroprojections of the friction surfaces of parts takes place during this period, and in this way, the area of their actual contact increases somewhat.

In the initial running-in period under favorable conditions, a sharp lowering of the specific pressure in the parts of the cylinder-piston assembly, a decrease in mechanical power loss, and a lower probability of subsequent appearance of sources of scoring on the operating surfaces are observed. Quite frequently in the process of initial running in, particles of metal and abrasive which are products of initial wear remaining following mechanical machining participate in the friction between the parts. These particles are incorporated in the working surfaces of the parts, and leave scratches and grooves in the fitted surfaces. Particles of chromium which are sheared off in the initial stage of running in of porous-chromed cylinder rings are particularly hazardous and numerous.

This stage of running-in is carried out as a rule on test stands and not under conditions of service. Special care is called for since very serious stresses on the friction surfaces of the parts can arise as a result of high specific pressures and high local temperatures, accompanied by insufficient lubrication. The local attack on the friction pairs in this case takes the form of chipping, smoothing, and shearing off of the surface unevennesses, over a very large area. The dislocation of these wear products causes surface damage. The presence of high local temperatures brings about plastic flow of the surface layers of the metal, and when the oil film is broken, scoring and seizing of the surfaces are promoted. This is what makes the initial period of running-in very important. Many researchers have hypothesized that this is the place to act to bring about subsequent wear resistance of the parts and long engine life.

Such a view, however, should be considered immoderate, since there is no set of conditions of running-in nor is there a type of break-in oil, as

research has shown, which can bring about increased resistance of friction surfaces to wear to any significant degree in such a short time, with the exception of cases where scoring has occurred in the initial running-in. The only measures possible in this area are means of preventing grooves and scoring and other surface damage, and those shortening the length of the period of initial running-in.

In the second period -- the period of completion of running-in -- the possibility of influencing the subsequent wear-resistance and life seems to be somewhat greater. In this period the very intensive processes of redistribution of residual stresses in the cylinder block and other parts, and the gradual evening off of microirregularities in the shape of the friction surfaces occur, and their optimal microgeometry is established, and relative stabilization of the clearances in friction pairs comes about. The intensity at which all these processes occur is controlled by the operating conditions of the engine and the type and quality of the oils and additives used, and it also depends upon the type of metallic coverings used for running-in, the chemical treatment of the friction surfaces, and a number of other techniques. This period of running-in occurs during service, but under reduced velocity and load conditions.

In the period of the completion stage of running-in, the various forms of initial wear are clearly manifested. A third period, called the period of settled wear by most authors, is not entirely appropriately named thus, hence the instantaneous rate of wear and tear -- which is the most objective criterion of the dynamics of the development of wear -- experiences small change only for a certain period, after which it monotonically increases. Accordingly, for classification of this third period, which ought to be called operational, it is preferable to subdivide it into periods of stable and gradually increasing wear and tear.

Experience shows that the period of stable wear and tear comprises only 7 - 10% of the entire period of operation of the engine up to major overhaul. It is characterized by relative constancy or negligibly small variation of all the basic indicators, in particular the effective power, the mechanical power loss, oil burning, blow-by of gases, etc.

The length of this period indicates the degree of perfection of the design, manufacturing technology, and operational methods of the engine, and serves as an initial criterion for evaluating the subsequent life time.

The period of gradually increasing wear and tear is the longest, and by nature characterizes the life time of the engine. The length of this period is inversely proportional to the growth of instantaneous wear and tear. The importance of operating technique -- starting conditions, operating conditions, timeliness of preventive maintenance, use of appropriate fuel and lubricants, etc. shows up particularly here.

The final, fifth period of catastrophic, or progressive, wear is very brief under conditions of correct operation. The onset of this stage indicates that a major overhaul is necessary, since in many cases further operation of the engine becomes unprofitable, both from the point of view of a loss in efficiency with respect to the operating parameters, and because of a sharp

increase in oil burning, blow-by of gases, and, consequently, increased conditions of toxicity.

All the classifications of the periods of wear and tear are determined by the variation in the wear, instantaneous rate of wear and tear, the effective power, the mechanical power loss, oil burning, blow-by of gases, and other indices.

One can base a classification of the types or wear of automotive engine parts on the basic characteristics of the conditions of friction and lubrication. These characteristics reduce to two basic types of friction: contiguous (semifluid) and fluid (hydrodynamic) friction. In contiguous friction, characterized by the presence of a very thin covering layer of oil, no more than 0.1 microns, the resistance to movement is determined by the value of the molecular interaction of the friction pair. Contiguous friction arises at low sliding rates and high loads. These fitted assemblies operate under such conditions: cylinder — upper piston ring, valve — valve guide bushing, cam — valve tappet, and other friction pairs.

In fluid friction, which is characteristic for crankshaft bearings, the oil layer takes on a lifting capacity, which guarantees the stability of the friction process. The friction course here is not determined by molecular interaction forces, but by the viscosity of the lubricant. Fluid friction is assured by the proper shape of the part surfaces, sufficient slipping rate, and relatively small loads.

Despite such varied and severe conditions relating to the friction and lubrication of parts, which are moreover intensified by the effect of a number of design, engineering, and use factors, researchers working on particular types of machines and relying on the classifications of wear types proposed by M. M. Khrushchov, I. V. Kragel'skiy, and B.I. Kostetskiy have in recent years attempted to devise a classification of wear in these machines. In this book. in the main, the classification of types of wear and tear of parts of automotive engines used is that proposed by M. M. Khrushchov and co-workers at his school. In this classification, mechanical, molecular mechanical, and corrosion-mechanical forms of wear and tear are differentiated.

Abrasive wear, in this classification, may be considered a type of mechanical wear and tear, in most cases of operation of parts linkages in automotive service. Some authors believe that this form of wear is the dominant form of operational wear of cylinders. Under this concept, products of wear and other abrasive particles must inevitably appear between the friction surfaces of parts, and act together with contaminants in the air or the lubricant. These hard particles plastically deform one or both of the friction surfaces of the parts, forming grooves of various depths and widths, scratches, or even broken-off pieces. Investigations of abrasive wear on cylinders have been carried out by K. R. Louis, S. Ye. Watson, N. F. Pochtarev, I. N. Velichkin, M. P. Zubietov, and many other specialists.

Another type of abrasive wear and tear in fitted parts of automotive engines takes place beside that one mentioned, when structural elements of the material of one part of a fitted pair act abrasively on the material of

the other. A typical example is the abrasive action of chromium particles from porous chromed piston rings on the active cylinder surfaces.

Wear resulting from plastic deformation, in which, under the action of a transmitted load, changes in the microgeometric dimensions of a part without loss of weight occur, is also regarded as mechanical wear and tear. The frequent deformations of cylinder sleeves, pistons, and rods are examples of precisely this form of wear.

Wear arising as a result of fatigue stresses under the action of regularly varying loads is also considered among the mechanical forms of wear and tear. This form of wear, accompanied by chipping of the active friction surfaces, arises most often on crankshaft bearing inserts.

Chipping is also encountered on the active cylindrical surface of piston rings, and shows up in a variety of forms of erosion degradations which are unconnected with fatigue phenomena. The cause of the erosion of piston rings, according to A. S. Mikeladze, is the occurrence of severe wear under conditions of boundary and even dry friction.

Some investigators explain these phenomena by local seizing of the metal, while others feel that they arise from gas corrosion, but V. F. Yankevich confirmed, on the basis of a number of studies, that the cause of the erosion is the formation of friable "white" layers on the piston rings, as a result of carburization of the metal of the rings under imperfect contact with the cylinder surface.

Thus, mechanical wear and tear is characteristic of many parts of automotive engines.

Molecular mechanical wear and tear, the characteristic signs of which are scoring and transfer of particles of metal from one of the fitted surfaces to the other, arises very often in fitted surfaces of parts of automotive engines.

It is well known that molecular action increases with increasing temperature; the degree of this interaction is influenced by the structure and, consequently, the hardness of the metals of the fitted parts. The scoring which occurs in the cylinders of automobile engines at the friction surfaces is often the consequence of the breaking of the oil film and of molecular seizing, judging from the iridescent tarnish which accompanies it. This form of wear can be considered among the molecular mechanical forms of wear and tear, in our classification. However, in the classification proposed by M. M. Khrushchov, the influence of the temperature factor is not considered, and in the case given it is entirely appropriate to designate this form of wear and tear as what B. I. Kostetskiy called heat wear or seizing wear of the second (II) kind.

Actually, in the severe friction conditions, aggravated by various deformations, in cylinders and piston rings the temperature in the upper zones may exceed the critical temperature of ordinary mineral oils, which is equal to 220° C. Above this temperature, such oils lose their useful properties, and no longer reduce the molecular interaction of the fitted surfaces of the parts. Some authors are of the opinion that metallic seizing of the material

of cylinders and piston rings is the basic factor determining the degree of cylinder wear. In order to increase plastic deformation, which enables seizing, it is recommended to choose alloys which have increased resistance to this phenonema, or to apply surface coatings which prevent seizing. The scoring of valve stems and valve guide bushings as well as of tappet heads and cams on the camshaft, which are often seen in examinations of engines, can also be classified as manifestations of typical forms of molecular mechanical wear and tear, which basically coincide with what B. I. Kostetskiy called seizing wear of the first (I) kind.

Evidences of corrosion which arise on the cylinder walls, in particular in cold starting of engines, and also as a result of the action of combustion products of the fuel, are typical instances of the corrosion-mechanical form of wear and tear.

The theory of corrosion wear of cylinders which was proposed by G. Rikerdo in 1933 was later expanded on and made more precise by K. Williams, A. Taub and other scientists. According to the current concept, corrosion wear in engine cylinders is caused by chemical or electrochemical processes.

Chemical, or so-called gas corrosion arises through the action of sulfur dioxide, oxygen, and oxygen compounds on the metal under conditions of high temperature. The essence of this type of corrosion lies in the presence in the medium of a compressed mixture of various acids -- among them formic, acetic, nitric, and carbonic, under conditions of high temperature; as well as aldehydes and other oxygen-containing compounds, carbon dioxide, sulpher dioxide, and water vapor.

These acids corrode the metal and the corrosion products are converted into friction compounds; thus, the wear acquires an abrasive character. Electrochemical, or acid, corrosion is a consequence of the action on the metal of electrolytes of sulfuric, carbonic, and other acids at lower temperatures. Coming into contact with the working surfaces of the cylinders, these acids destroy the structure of the surface coating, and the corrosion film formed on the surface is continuously removed by the piston rings, increasing the intensity of wear.

Electrochemical corrosion occurs to a still greater degree when fuels with sulfur content are used. For engines which operate under varying conditions of speed and load, the content of sulfur in the fuel should not exceed 0.2 to 0.4%. A limiting value of under 0.1% should be aimed at.

The theory of the predominant influence of corrosion on the wear of cylinders of automobile engines is advocated by many domestic and foreign investigators.

Some of these have remarked that corrosion wear and tear is characteristic not only for cylinder walls and piston rings but also for other friction surfaces, among them crankshaft bearings. However, other investigators, in particular L. Dem'yanov, while confirming the increase in wear intensity when

thermal conditions in the engine have decreased, explain this relation not through corrosion phenonema but by a change in the properties of lubrication and the friction surfaces.

The work of I. M. Lenin, I. Ya. Raykov, I. I. Sidorin, and I. L. Zubarev, which determine the effect of the flow of hot fuel mixture on wear of cylinder walls, formed the connecting link between the "corrosion", "abrasive", and "molecular" theories of wear as explanations for the unevenness of wear distribution circumferentially and the development of "peak wear".

There are many other investigators who have confirmed the predominance of either corrosion or abrasive wear of cylinders and piston rings; as well as wear by seizing. However it is expected that each of these forms of wear can occur predominantly or concomitantly, depending on the conditions of use of the motor vehicle. Therefore the contradictions between the adherents of the various theories of the origination of the types of wear are not fundamental.

In general, it should be noted that the currently used methodology of classifying types of wear into predominant and concomitant is very convenient for analysis of phenomena of wear and tear of samples made of various materials at various speeds and loads, but not in internal combustion engines. It happens that the extremely rapid change in the operating conditions of parts under the unsteady operating regimes which prevail causes such a frequent change of the conditions which lead to one or another type of wear that there is no opportunity to make the distinction between predominant and concomitant forms.

In connection with this, the development of various measures to increase the life of engines is possible only by considering the various forms of wear separately, and completely covering all three basic forms: mechanical, molecular-mechanical, and corrosion-mechanical wear and tear.

Life of Various Automotive Engine Models

Life of an engine is determined by the extent to which it preserves its working capacity up to the terminal state -- with the necessary interruptions for technical servicing and repair. The stastical index of engine life is the average running time up to the first major overhaul. In this overhaul the basic groups of parts are treated according to an established scheme of overhaul parameters. In particular, the cylinders of the engine block are bored out and honed, the crank pins are reground, and new bearing inserts are installed. On the whole, the concept of life time is governed either by a limiting decrease in efficiency or by requirements of safety and economy.

The optimal limits of operation of various models of engines still cannot be considered to have been established; consequently, the annual losses on the national scale are estimated in the millions of rubles.

These losses are mainly the result of insufficiently objective evaluation of the terminal technological state of the engine, whereupon the latter is sent to major overhaul without urgent necessity.

In practice, the need for major overhaul of an engine is usually based on a drop in power, an increase in the rate of fuel and oil consumption, smoking, an increase made in the noise by fitted parts, drop in oil pressure, etc.

At the same time, the power of an engine falls a small amount along with wear, sometimes the fuel consumption does not increase, an increase in the rate of oil consumption is possible due to leaks in the crankcase seals and gaskets, and oil pressure may drop as a result of wear on parts of the oil pump.

There are literature data to the effect that, following 100,000 km of service of a motor vehicle, the power of the engine may be reduced by 3% overall, and the rate of oil consumption may be reduced by 7% or more by the removal of scale from the gaps in the piston rings. This is evidence that major overhaul of the engine is not necessary.

All the above are primary factors which complicate generalization and statistical treatment of the information about life times of engines.

Another factor is the extreme scatter in the amounts of wear, not only in various models of engines, but even in engines of the same model or in duplicate parts on the same engine.

Thus, the comparison of life times of various models of Soviet automobile engines is a complex problem; and it is particularly hard to compare this statistic with that for foreign motor vehicle engines. This difficulty is explained by the extreme variation in conditions of use. The latter is described in the literature, and reduces to the following:

1. Most countries have relatively more favorable and less variable climatic conditions, as well as road surface conditions. Europe and areas of the USA have a favorable effect on the life time of foreign motor vehicle engines. Predominance of cold climate in our country over warm (in a ratio of 84:16%) promotes more intense corrosion wear of cylinders, to a significant degree, and the absence of good roads and the dustiness of the surrounding air favor the growth of abrasive wear of basic parts and fitted assemblies.
2. The rather high intensity of operation of motor vehicle fleets in the USSR in comparison with fleets in foreign countries also lowers the life time of Soviet engines, hence the frequent changes of loads and rpm promote increased wear of parts associated with the cylinder and piston, and degradation of bearings and other parts.
3. The not always satisfactory quality of materials used, the insufficiently wide application of specialized and multifunctional additives to the oil, the low quality of overhaul work, and the untimeliness of preventive maintenance also shorten the service time of domestic motor vehicle engines in comparison with foreign ones.

In short, the conditions of service of motor vehicle engines govern to a large degree the appearance of various types of wear.

Comparisons sometimes encountered in literature which favor foreign models in their engine life are not always completely objective, since they omit the

conditions of service of the motor vehicle. In this regard, the experience of utilization of foreign motor vehicles on our territory in the Second World War was very telling; the engines displayed very low life times. Thus, Studebaker automobile engines required major overhaul after a service life of 40,-50,000 km, Chevrolet -- after 10,-20,000 km, Willys -- after 10,-12,000 km, etc. There are also data on the results of use of automobiles of various brand names in different regions of the USSR in 1955-1959. Thus, "Hercules" engines on "Diamond" automobiles had a period of service before major overhaul of 125,000 km, "MAK" engines -- about 135,000 km and " Tetra 111" -- between 50,000 and 60,000 km, etc.

Comparative road tests, carried out on a limited scale, of certain models of foreign and domestic engines typically have held them to have comparable engine lives; this applies even more with respect to diesel engines.

A number of methods are used to evaluate engine wear and engine life; these are described in detail in Chapter II of this book. Complex data on the amount of oil burning and the blow-by of gases are considered the most objective indicators, under conditions of vehicle use; also the rate, or average rate, of wear and tear (specific wear) which limit the life of parts and, chiefly, cylinders.

The rate of wear and tear of the cylinders in an engine varies depending on the type and design of the motor vehicle in which the engine is installed. It varies markedly under the influence of operating conditions and also time of operation. Consequently, the evaluation of life time is sometimes accompanied by large errors.

Indeed, according to previously published data, ZIS-5 engines on ZIS-5/8 buses, operating on highway routes, had a specific cylinder wear of 13.8-14.7 microns/1000 km, and in operation under urban conditions, 18-34.8 microns/1000 km, while the rate of wear and tear of engines on the identical type of vehicles during long trips was 6-8 microns/1000 km.

Specific wear of cylinders of ZIL-120-124 engines installed on ZIL-150, -151, -155, -156, -585 and other vehicles, used on short trips, was 7.1-7.4 microns/1000 km and in operation of the engines on buses over long nonstop runs, it did not exceed 3.4-9 microns/1000 km. An analogous example may be given for GAZ-51 engines used on identical types of automobiles under varying conditions. When they were used in highway transport, the rate of wear and tear of the cylinders was 1.1-1.2 microns/1000 km; under urban conditions, it was 3.3-4.1 microns/1000 km; under road tests, 3-3.5 microns/ 1000 km; in road tests under severe conditions over several months 8-9 microns/ 1000 km; and under relatively favorable conditions of use over a period of service of 30-50 x10^3 km, 1.5-4 microns/1000 km.

The variation of rate of wear and tear of cylinders of engines of different periods of vehicle service even under identical service conditions has its individual peculiarities. Thus, for cylinders of GAZ-M-20 engines, there was characteristically a rise in the rate of wear and tear during a service mileage of up to 100,000 km, followed by somewhat of a decrease. In GAZ-21 engines it tends to decrease continuously with running time until the period of terminal wear; however, not in a regular way, since not only is engine design a factor but also

All of this is evidence that estimation of engine life from the rate of parts wear is an approximation, and it is a complex matter to generalize about the sometimes contradictory information on this question.

R. V. Kugel' studied a large number of Soviet and foreign data and established the following average values of rate of wear and tear of cylinders of contemporary motor vehicle engines when operating instructions are observed: freight trucks, used on long daily runs under favorable thermal conditions -- 3-4 microns/ 100 [sic] km; under varying conditions, primarily fairly short average daily runs -- 4-6 microns/1000 km; and on short trips with frequent stops and unfavorable thermal conditions -- 6-8 microns/1000 km. Automobiles with small displacement have an average rate of wear and tear of 4-7 micron/1000 km; with medium displacement, 4-5-5.5 microns/1000 km; and with large displacement around 3 microns/1000 km.

The rate of wear and tear of carbureted engines used on motor vehicles under urban conditions with frequent stopping and uneven operating conditions lies in the limits of 3-5 microns/1000 km; that of cylinders of diesels under the same conditions in the limits of 2-3 microns/1000 km. For the latter, when used for long runs with infrequent stopping, the rate of wear and tear is 1.5-3 microns/ 1000 km.

In this the author has taken as the terminal value of wear of cylinders in engines of trucks and buses 300 microns, and for automobile engines with small, medium, and large displacement 250, 300, and 400 microns, respectively. The data presented, despite their tentative character, are of great value from the point of view of the possibility of using them to compare types of wear and tear of cylinders of various engines, including obsolete engines, those becoming obsolete, and models which are relatively in the design stage.

Values of the average rate of wear and tear of cylinders and other parts of a number of models of engines, based on relatively favorable conditions of use in the interval 30,-50,000 km of service life of motor vehicles, generalized from our data and the literature sources, are presented in Table 2. Data on relatively new models of engines cannot be presented, since the present correlations are possible only with results of the operation of a large number of vehicles over many years.

Because of the extremely wide scatter in the absolute and specific values of wear, the data of this table and of those following are approximate.

The rate of wear of 4-cylinder flathead GAZ engines was lower than that of 6-cylinder GAZ-51 and GAZ-63 engines installed in freight vehicles. Briefly, this can be explained by a lower tendency to deformation in the 4-cylinder blocks, a somewhat greater uniformity in their temperature fields and in distribution of oil among the cylinders, the fact that the connecting rods in GAZ-69 and UAZ-450 engines are symmetrical, more rigid crankshafts with dirt traps, and operating conditions which were more economical from the standpoint of engine life.

The least rate of wear and tear in engine cylinders occurred in GAZ-21, primarily as a result of the relatively short stroke of this model, and the use of wet type cylinder sleeves, which have a more even temperature field around the circumference.

Table 2.

Таблица 2

a Темп износа мкм/1000 км	b ГАЗ-51 ГАЗ-63	c ГАЗ-69 УАЗ-450	d ГАЗ-21	e ЗИЛ-120 ЗИЛ-164	f ЗИЛ-124 ЗИЛ-158	g МЗМА-407
h Цилиндры	1,5—4,0	1 2—3,5	1,0—3,0	5,0—5,5	3,2—3,5	2,0—3,0
i Верхнее кольцо по толщине	3,0—7,0	3,0—7,0	2,0—6,0	10,0—15,0	7,0—12,0	1,0—3,0
j Верхнее кольцо по высоте	1,0—2,0	0,2—0,5	0,2—0,4	1,0—2,0	1,0—2,0	0,2—0,8
k Верхняя канавка по высоте	0,5—1,0	0,5—1,0	1,0—2,0	1,0—2,0	1,0—2,0	0,5—0,8
l Коренная шейка коленчатого вала	0,5—2,0	0,5—1,5	0,3—0,8	0,5—4,0	0,5—4,0	0,2—0,5
m Шатунная шейка коленчатого вала	1,0—3,0	0,5—2,0	0,2—0,5	1,0—6,0	1,0—6,0	0,7—1,0

a, Rate of wear, microns/1000 km; b, GAZ-51, GAZ-63; c, GAZ-69, UAZ-450; d, GAZ-21; e, ZIL-120, ZIL-164; f, ZIL-124, ZIL-158; g, MZMA-407; h, Cylinders; i, Upper ring, thickness; j, Upper ring, height; k, Upper piston groove, height; l, Crankshaft main journal; m, Crankpin.

The tendency of these sleeves to deform substantially acts against any substantial lowering of wear of the cylinder rings, and even promotes some increase in the rate of wear and tear of cylinder grooves.

The cast steel crankshafts of GAZ-21 engines with spaces in the crankpins for catching wear products and with crankpins having propitiously chosen diameters ensure a low rate of wear and tear of the crankpins, even lower than normal in comparison with the main journals.

In comparison of parts of ZIL engines, a somewhat lower rate of wear and tear of cylinders and radial wear of piston rings is noted on ZIL-124 and ZIL-128 models installed on buses, in comparison with the truck models ZIL-120 and ZIL-164. This is because the operating conditions on buses are more favorable, particularly when making long trips on quality highways.

The rate of wear and tear of the basic parts of the MZMA-407 engine is outstanding among the engine models presented in the Table, comparable to that of the GAZ-21 engines in the "Volga" vehicle.

The above data, which describe the rate of wear and tear of friction surfaces which limit the service life of parts of various engine models are not sufficient to completely describe service lives. In order to make such an evaluation we need a systematic relation between the technical and economic indices of the engines, data on oil burning and blow-by of gases, maximum allowable

wear of parts and clearances and fitted assemblies[5], and the limiting deformations of the basic parts. At present we have only isolated data from service experiments and the results of a number of theoretical and experimental investigations of these relationships; these are given in Table 3.[6]

Table 3.

a Предельные параметры долговечности	GAZ ГАЗ-51 ГАЗ-63	UAZ УАЗ-69 УАЗ-450	GAZ ГАЗ-21	ZIL ЗИЛ-120 ЗИЛ-164	ZIL ЗИЛ-124 ЗИЛ-130	MZMA МЗМА-407
b Пробег до 1-го капитального ремонта, тыс. *км*	80—100	80—100	130—170	80—120	120—160	70—100
c Угар масла, *л*/100 *км*	1,0—1,2	0,6—0,8	0,5—0,7	1,3—1,5	1,3—1,5	0,2—0,3
d Пропуск газа, *л/мин*	100—110	75—80	120—130	120—130	120—130	—
e Износ цилиндров, *мм*	0,40—0,45	0,25—0,30	0,25—0,35	0,45—0,50	0,45—0,50	0,20—0,30
f Износ верхних колец по высоте, *мм*	0,20—0,25	0,20—0,25	0,20—0,25	0,20—0,25	0,20—0,25	0,20—0,25
g Износ коренных шеек коленчатого вала, *мм*	0,15—0,20	0,15—0,20	0,15—0,22	—	—	—
h Износ шатунных шеек коленчатого вала, *мм*	0,22—0,25	0,22—0,25	0,10—0,20	0,22—0,25	0,22—0,25	0,15—0,18
i Зазор цилиндр—поршень, *мм*	0,4—0,5	0,4—0,5	0,3—0,4	0,3—0,5	0,3—0,5	0,2—0,3
j Зазор верхнее кольцо—канавка, *мм*	0,15—0,25	0,15—0,25	0,15—0,30	0,15—0,20	0,15—0,20	0,10—0,20
k Зазор коленчатый вал—подшипник, *мм*	0,20—0,30	0,20—0,25	0,20—0,25	0,27—0,30	0,27—0,30	0,15—0,18

a, Limiting parameters of engine life; b, Service mileage to 1st major overhaul; c, Oil burning, 1/1000 km; d, Gas blow-by, 1./min; e, Cylinder wear, mm; f, Wear of main crankshaft journals, mm; h, Wear of crankpins, mm; i, Clearance between cylinder and piston, mm; j, Clearance between upper ring and groove, mm; k, Clearance between crankshaft and bearing, mm;

From the table it is seen that the maximum allowable values of wear of parts of different models vary mainly with respect to the cylinder walls. Thus, for cylinders of GAZ engines in trucks the limiting value is 0.40-0.45 mm; for GAZ-M-20, GAZ-69, and UAZ-450 engines and their modifications the cylinder bore is suitable when a wear of about 0.25-0.30 mm has been attained; for cylinders of GAZ-21 engines a wear of 0.25-0.35 mm is acceptable; etc.

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5 [Translator's note: The author appears to be using the terms "limiting", "maximum allowable", and "terminal" interchangeably.]

6 The data in Table 3 are from the years 1962-1968.

Beside the maximum allowable values of wear, the parameters which limit engine life are deformation of the shape of cylinders and crankpins.

In the practice of overhauling domestic engines, the maximum permissible out-of-round of the cylinder shape, in particular, ovality, is 0.1 mm, and that of crankpins is 0.05 mm. The effect of these parameters on the terminal operating indices of engines is not yet well understood, and requires further study.

On the basis of an analysis of the life times of foreign and domestic engines, R. V. Kugel' predicted the possible service lives of engines of vehicles of various types in the design stage, taking into account service under various conditions. According to Kugel', the basic service life before the first major overhaul of engines on various types of trucks with load-carrying capacities of 0,25 tons to 12-14 tons should be 100 - 260x10^3 km. Assuming these values, the approximate terminal wear in cylinders should be between 0. 25 and 0.5 mm at an average wear rate of 2.0-2.5 microns/1000 vehicle km. On automotive engines with very small, small, medium, and large displacements, the engine lives should be 70-80, 100-110, 140-150, and 240-250x10^3 km. Accordingly, terminal wear in the cylinders should not exceed 0.2, 0.25, 0.3, and 0.4 mm; with wear rates being 2.8, 2.1, 1.8, and 1.8 microns/1000 vehicle km. Engines of buses in delivery, urban, and interurban transit should have service lives up to the first major overhaul of 250-260, 300-320, and 350-400x10^3 km, respectively, with a terminal cylinder wear of 0.5 mm, and wear rates of 1.9, 1.5, and 1.2 mm/1000 vehicle km. A planned extension of engine life is possible if a number of design, engineering, and use methods, some of which appear in the subsequent chapters of this book, are put into effect.

At present, a critical situation has arisen with regard to life of engines after major overhaul; under existing overhaul methods this life does not exceed 30-55% of the life of new engines (Fig. 6).

According to the engineering specifications for overhaul of engines the same tolerances for the various variations from the cast dimensions, and also from roundness, cylindricity and other parameters are usually observed as for new engines. Accordingly, approximately the same life times of the engines after major overhaul might be expected as of new engines. But, as was mentioned earlier, major overhaul does not assure the expected service life of an engine; this was also shown in specially accelerated experiments, the results of which appear in a later chapter of this book.

Main factors behind this situation are the low level of engineering sophistication of the vehicle repair industry, a lack in that industry of the necessary nomenclature, supplies of spare parts of the needed dimensions, and insufficient design accommodation of the engines to a good overhaul process.

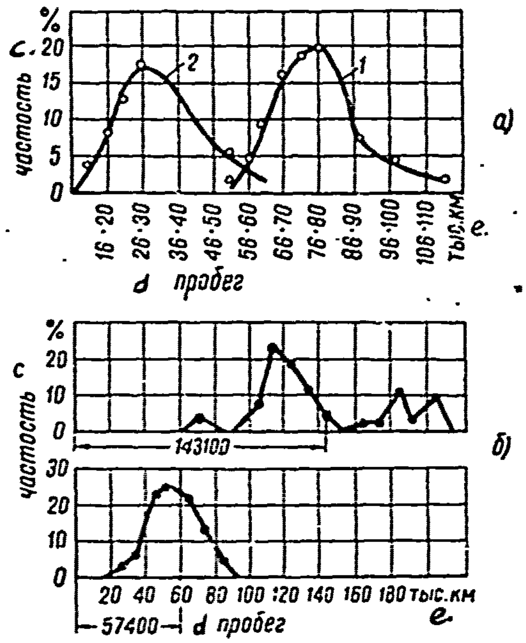


Fig. 6. Engine life distribution curves:

1 -- new engines; 2 -- after major overhaul; a -- M-20 engines (from data of R. V. Kugel'); b -- GAZ-21 engines (from data of P. L. Chervonobrodov)

Key: c, frequency; d, service mileage; e, 10^3 km.

Table 4.

Engine life, in km of vehicle travel [sic]	GAZ-51	GAZ-69, UAZ-450	ZIL-120	ZIL-124
To 1st major overhaul	80-100	80-100	80-120	120-160
To 2nd major overhaul, after 1st	30-40	30-40	30-50	50-80
% this represents of vehicle travel to 1st major overhaul	35-40	35-40	35-41	40-50

Chapter II

Methods of Evaluating Engine Wear and Engine Life

Prerequisites for Calculating Engine Wear and Engine Life

Knowledge about machine wear and machine life has developed, in the main, empirically. At present it is in a stage of development where the time is ripe for the creation of methods of calculation. One should be able to solve the following questions, based on prior calculations: setting norms for the life times of machines in the design stage, insuring evenness of wear of friction surfaces, comparing various design forms from the point of view of wear resistance, development of systematic methods of repair and operation of machines, etc. To some extent these problems are in a state of being solved for separate parts and fitted assemblies thanks to the voluminous efforts of A.S. Pronikov, M.M. Khrushchov, B. Ya. Gintsburg, I.V. Kragel'skiy, V.N. Treyer and other scientists. Meanwhile, for internal combustion engines, whose operation is associated with steady speed and load conditions, large temperature gradients, and varied lubrication conditions, the problem of devising methods of calculation of wear and engine life is far from being solved. This results from the fact that relationships governing wear and tear of the various friction surfaces are undetermined, and there are no reliable data concerning limiting standards of wear for the basic parts.

Therefore, an exposition of the known material reduces simply to a summary and brief analysis of certain criteria which are prerequisites for the devising of calculations of engine wear and engine life.

These criteria can be divided into three basic categories:

a) Criteria which determine the relationship between friction and wear in metal-metal interactions, under conditions of various media, speeds, loads, and temperatures;

b) Criteria which characterize the wear of parts during various periods of operation of the engine, and which determine the effect upon wear

of design, engineering, and use factors;

c) Criteria which enter into the calculation of optimal engine life, taking into account economic efficiency and the need for major overhaul.

The elements of the first category are chiefly the three criteria of wear intensity which were proposed by I.V. Kragel'skiy[7]:
linear intensity

$$I_h = \frac{h}{l} = \frac{v}{l\,Aa};$$

gravimetric intensity

$$I_g = \frac{g}{l\,Aa};$$

energetic intensity

$$I_w = \frac{v}{W_f} = \frac{v}{Fl}.$$

In these expressions:
h is the depth of the worn layer,
l is the friction path,
v is the volume of the worn material,
Aa is the nominal contact area,
g is the weight of the worn material,
W_f is the work done by the friction force,
F is the friction force.

The author has offered several functional relations for calculations in the evaluation of the effect of various factors upon wear. Thus, wear is represented as a function of the load in general form by the expression $I=Kq^x$, where q is the specific load on a friction pair, kilogram per centimeters squared.

As the load is increased, the exponent decreases and the multiplier K increases.

These and many other formulas and criteria mentioned in the fundamental work of I.V. Kragel'skiy, while undeniably valuable for theoretical and experimental work in the field of friction and wear of test pieces and individual parts

[7] In the formulas given in this chapter, some of the notation has been changed from the original, to facilitate presentation of the material.

of machines, still cannot be recommended for the practical evaluation of wear resistance of future parts operating under conditions of sharply varying pressure, temperature, and speed.

Professor A.S. Pronikov developed methods of calculation of the lifetime of certain machine parts, in particular, machine tool parts. The basic aim of these calculations is:

a) Find a relation which will determine the shapes of the worn surfaces of fitted assemblies of various design shapes on the basis of the laws governing wear and tear of the material;
b) Establish the maximum allowable wear and service time of parts, depending upon their function in the mechanism and in the machine.

These methods of calculation were used by A.S. Pronikov in a number of theoretical investigations. Thus, to describe abrasive wear of discs under conditions of constant contact surface, the author used the wear formula;

$$U = K\frac{Pn}{R-r}t,$$

where P is load,
n is the relative rpm,
R and r are the maximum and minimum radii of the discs,
t is the wear period,
K is a constant multiplier.

Laboratory experiments, conducted at the Institute of Machinery Science, on wear in friction pairs in the absence of the effect of supporting oil, determined the wear rate as a function of the mutual pressure of the friction surfaces P:

$$\frac{dl}{dS} = CP^m,$$

where dl is the change in the linear dimension of the part undergoing wear,
S is the friction path, and
C and m are constants which depend on the friction conditions; m lies between one and two.

For semifluid friction, M.M. Khrushchov gave this expression in the form

$$\frac{dl}{dS} = CP\left(1 - K\frac{v\eta l}{h^2 p}\right),$$

where K is a coefficient which characterizes the conditions producing the hydrodynamic pressure in the oil layer,
v is the rate of sliding of the friction surfaces,
η is the viscosity of the oil, and
h is the minimum clearance between the friction surfaces.

The value of $K\frac{v\eta l}{h^2 p}$ characterizes the part of the overall force on the friction pair which is transmitted through the oil layer.

These expressions are the starting points for the criteria of engine parts wear proposed by B. Ya. Gintsburg, and the basis for the equations for calculating wear and tear of piston rings which were derived by him. There have also been a number of other investigation in which authors have proposed various criteria and expressions for evaluating wear resistance of metals and rates of wear and tear of fitted assemblies; these contained such parameters as internal energy, energy coefficient of friction, etc., which limits practicability.

The chief criterion characterizing the period of wear and tear and the influence of various factors upon wear has to be the criterion of initial wear, or of full running-in. Criteria of this type can be represented as the quotient of the change in certain indices from their initial values to relatively stable values and the time τ consumed in this process under set conditions of running-in of the engine and with other conditions being equal. These certain indices may be, for example, the smoothness of the surfaces R_a, the mechanical power loss N_{mp}, oil burning G_o, gas blow-by G_g, rpm of the crankshaft at starting n_x, and a number of other indices. Then the criteria of initial wear, or break-in, take the form:

$$K_{пр}=\frac{R_a^{пр\,a}-R_a^{исх\,b}}{\tau}=\frac{N_{мп}^{пр}-N_{мп}^{исх}\,c}{\tau}=\frac{G_м^{пр}-G_м^{исх}\,d}{\tau}=$$

$$=\frac{G_г^{пр}-G_г^{исх}\,e}{\tau}=\frac{n_п^{пр}-n_п^{исх}\,f}{\tau},$$

Key to subscripts and superscripts: a=s, b=i, c=mp, d=o, e=q, f=x

The superscripts i and s correspond to the initial and final conditions.

When the concentration of iron in the lubricating oil is used to evaluate initial wear and so-called "wear lines" are plotted the criterion of engine break-in is the arbitrarily fixed wear resistance $1/\tan\alpha$, where α is the angle made by the straight part of the wear line with the abscissa.

The break-in criterion in this case can be expressed by the ratio

$$K_{пр}=\frac{G_{ж}-a}{S},$$

Key: a=Fe

where G_{Fe} is the amount of iron (g) removed from the friction surfaces during the break-in period of the engine, and S is the overall excursion of the piston (km). Accordingly, an increase in the numerator or a decrease in the denominator indicates intensification of the break-in process.

The achievement of optimal clearances in fitted assemblies of parts during the running-in process is an entirely objective criterion of initial wear. For this one must have information about the values of the optimal clearances Δ_{op} of each of the fitted assemblies separately, data on initial nominal clearances Δ_i, and on the rate of increase of clearances $\tan\alpha$ or the break-in time τ. The break-in criterion[8] then has the form:

$$K_{\text{пр}} = \frac{\Delta_{\text{опт}} - \Delta_{\text{нач}}}{\text{tg}\,\alpha}, \qquad K_{\text{пр}} = \frac{\Delta_{\text{опт}} - \Delta_{\text{нач}}}{\tau}.$$

Key: (subscript) *a* = op, *b* = tan

Investigators have also proposed a number of indices and criteria in the area of evaluating the influence of various factors upon wear.

Thus, D.P. Velikanov proposed considering the following as indices which indirectly connect values of parts wear with the time of their service and which characterize driving forces, modes, and conditions of operation of basic parts of an engine:

1. The rpm of the crankshaft and the [friction] distance it travels per km of vehicle travel with a direct transmission.
2. Average velocity of a piston at the rpm corresponding to maximum power.
3. [Friction] distance traveled by a point on the working surface of a crankpin per vehicle km.
4. Maximum sliding rate of the working surface of the crankshaft journals in the bearing.
5. Maximum specific pressure on the connecting rod journals.

In the opinion of B.Ya. Gintsburg, the average speed of the piston V_p, which characterizes the values of the pressures which build up on the working surfaces of parts, only in certain cases is part of the compound parameter which determines the life time T_0. Other quantities in this parameter are the diameter of the cylinders D, the ratio of the stroke to the cylinder diameter S/D, and other design parameters.

Starting from the similarity of wear phenomena plus a number of assumptions, and statistical treatments of data, B. Ya. Gintsburg arrived at criteria for wear and life times of cylinders, piston rings, crankshaft bearings, and parts in the valve mechanism.

The criteria for cylinders have the form:

$$T_0 = \frac{3}{\alpha}\,\frac{D}{n}$$

---

[8] [Translator's note: The word "criterion" is often used in this book in the sense of "characteristic number."]

or, introducing the average piston speed,

$$T_0=\frac{\delta}{\alpha}\,\frac{S/D}{V_{n\,\alpha}}\,D^2,$$

Subscript key: α = p

where δ is the relative terminal value of radial wear, α is the "reduced" value of the coefficient of proportionality between the operating time and the wear, and n is the rpm of the crankshaft.

The author noted that the value of δ/α may be considered constant for each part of engines of similar design which work under identical conditions.

The expression

$$T_0=\frac{\delta}{\alpha}\,\frac{D}{V_n},$$

was proposed as a criterion of terminal wear of piston rings in their radial thickness, and the expression

$$T_0=\frac{1}{n}\sqrt{\frac{\delta}{\alpha}D}$$

was proposed to evaluate wear of piston rings and piston grooves in their height; expressing this by using the average piston speed,

$$T_0=\frac{S/D}{V_n}\sqrt{\frac{\delta}{\alpha}D^3}.$$

Considering only the action of initial forces and neglecting the force of gas pressure, the author proposes a criterion for the life of crankshaft bearings:

$$T_0=\frac{\delta}{\alpha}\,\frac{(S/D)}{V_n^3}\,D.$$

Analogously to the above, an expression for parts in the valve mechanism was proposed:

$$T_0=\frac{\delta}{\alpha}\left(\frac{S/D}{V_n}\right)^{2m}\cdot\frac{1}{n}.$$

The above criteria characterize the dependence of the life time on a number of design parameters and indicate the advantage of using moderate rpm, medium speeds, not-too-small ratios of stroke to cylinder diameter, and, as much as possible, large cylinder diameters.

In addition, the author emphasizes that all these criteria were derived under simplified assumptions, and do not take into account the significant influence on engine life exerted by temperature factors and fatigue phenomena.

Other authors have advocated using the universal formula proposed by A.N. Ostrovtsov for determining the life of engines operating under binary friction:

$$T_o = \frac{\Delta \max}{\gamma k_\Sigma}$$

where $k_\Sigma = k_1, k_2, k_3$, etc., the latter being factors of material, hardness, temperature, surface smoothness, precision of fit, oil quality, and factors depending upon operational conditions. Here γ is the intensity of wear and tear, given by

$$\gamma = A \, P_{qa}^{\lambda} \, S_f^{\mu}$$

A is a proportionality coefficient,
Δ is the terminal wear,
P_{qa} is the specific pressure on the friction surfaces, and
S_f is the length of the friction path.

For calculating the life of machine parts, V.N. Treyer recommends the use of the unified formula

$$C = P(nT_o)^k$$

where C is the performance capability of the part,
P is the load, or a factor describing the specific conditions of loading of the part,
n is the rpm of the shaft [sic] , which is proportional to the number of cycles per minute of loading or of friction which the part in question undergoes,
T_o is the life time of the part, hours of operation, and,
k is an exponent determined empirically.

P.I. Kozlovskiy considers the chief external factors determining the wear of parts of the connecting rod-crankshaft mechanism and the cylinder-piston group to be the mean effective pressure P_e, the total number of revolutions, and the rate n of revolution of the crankshaft, as well as the time t and the surface temperature of fitted parts:

$$Y = f(P; n; t; T).$$

The suggested comparison of wear under various conditions on the basis of this approximate relation is extremely complicated to carry out in practice. It is even more difficult to apply fuel consumption relations, under equivalent

or initial conditions, for approximate calculation of wear coefficients, since fuel consumption depends more on a number of other factors than on engine wear.

The investigator I.I. El'ovich also associated the intensity of engine wear and tear with the average speed of the piston V_p and the average effective pressure P_e. He proposed the following relation, experimentally verified on a YaAZ-204 engine, for the conditions n = 100-1900 rpm and P_e = 2-5 kg per cm^2.

$$J = AP_e^2 V_p^{2/3} \quad ,$$

where A is a coefficient depending on the individual properties of the engine and the overall anti-wear effectiveness of the lubricating oil.

F.M. Klemushchin proposed an approximate formula to find the wear, in which the diameter of wrist pins is a factor

$$I = K_1 P_m^{x_1} V_o^{x_2} d_p^{x_3} m^{x_4} H_v^{x_5} t^{1/2}$$

[exponents $x_1 \ldots x_4$ illegible in original]

where K_1 is a coefficient accounting for the operating conditions and other factors,
P_m is the average pressure on the (wrist) pin at the small end of the connecting rod, km per cm^2,
V_o is the relative sliding speed of the pin, m/sec,
d_p is the diameter of the pin, centimeters,
m is the stroke time coefficient,
H_v is the Vickers hardness of the wrist pin, and
t is the operating time of the engine, in hours.

In recent years, mathematical statistics has been increasingly used to estimate the freedom from breakdown and life time of machines. Looking at the buildup of wear as a stochastic process, researchers have determined the correlation between wear and length of service of a part. Thus, a parabolic equation has been proposed for the correlation:

$$I = K\sqrt{t} \, ;$$

where I is wear,
K is a constant,
t is running time.

Along this line, another correlation is more promising, namely, the exponential wear equation of I.B. Tartakovskiy, which he proposed to describe the wear and tear of cylinders, pistons, piston rings, and crankshaft bearings.

This equation has the form

$$\delta = (\delta_0 + h) \cdot 10^{\frac{t - t_0}{A}} - h,$$

where δ is the current value of the wear, t is the length of time of operation, δ_0 is the wear after an arbitrarily chosen interval t_0, with t_0 greater than the running-in time, and A and h are constants which depend upon the engine model and the particular part, as well as on the parameter with which the equation is concerned. Mathematical treatment of some parts wear measurements taken by I.B. Tartakovskiy at the Gorki Motor Vehicle Plant demonstrated the validity of his equation.

The pr..aary members of the third category of criteria which constitute prerequisites for the calculation of optimum engine life and establish the practical overhaul requirements of engines would have to be the expressions characterizing the terminal clearances in fitted parts. In this connection the work of M.S. Belitskiy is of great interest. Starting with the hydrodynamic theory of lubricants, and taking the preservation of the oil film as the criterion, he proposed a formula for finding the maximum allowable clearances in the fitted assembly comprised of the cylinder surface and the piston skirt:

$$h = l^1 \sqrt{\frac{12\eta}{t P_z}};$$

where η is the absolute viscosity of the oil,
P_z is the maximum pressure of gases in the cylinder,
t is the time the hot gases act upon the oil film, and
l^1 is the height of the lower part of the piston skirt.

Results of comparing experimental data with calculations according to this formula permit recommending it as a criterion which determines the need to change pistons.

As of today many research results have been published devoted to the determination of the optimal life time and economics of operation of machines. Thus, N.D. Meshkov, analyzing the expression for evaluating the service time between overhauls of automotive engines which was proposed by G.A. Kurguzkin, has modified it to take into account unsteady and startup modes of operation:

$$T_{\kappa} = (\rho + 1) \frac{\pi \cdot \gamma \cdot d_0 \cdot S \cdot \Delta l_r}{0{,}42 \cdot \beta \cdot (W_p + W_{\kappa})},$$

where T_r is the amount of maintenance between major overhauls;

γ is the density of iron, g/mm^3,

d_0 is the nominal cylinder diameter, mm,

S is the stroke, mm,

Δl_t is the terminal wear of the cylinder sleeve in the upper zone, mm,

W_g is rate of total wear of the engine, g/hr, found by composition by weight in the "iron in oil" method, for unsteady conditions, and

W_q is the rate of total wear of the engine, g/startup [sic], in the startup regime, with β a coefficient accounting for engine wear under unsteady conditions. This proposed equation deserves attention, however it requires a knowledge of the quantities W_g and W_q, and it is a complicated matter to determine these.

To determine the estimated optimal period between breakdowns of parts, I.A. Mishin has proposed a simplified expression

$$T_э = \sqrt{\frac{2W_1}{\Delta W} t},$$

where W_1 is the initial output per unit time,

ΔW is the decrease in output per unit time, and

t is the cost to restore the performance capability, equivalent to the labor cost of the restorer, hrs. The author also recommends formulas for determining optimum machine life in the case of uniformly accelerating gradually increasing costs of restoring performance capability. The examples he gives of calculations indicate that the recommended expressions are feasible. Relations for calculations for evaluating the optimal life time are also given by M.M. Mikhaylovskiy, Yu. S. Rakhubovskiy, and other researchers. Thus, at present, we already have a substantial number of criteria and mathematical relations which, upon further supplementation and generalization, will form the basis of calculations of motor vehicle engine wear and engine life. It may be assumed that, with time, such calculations will be accepted into engineering practice as strongly as formerly calculations of static rigidity and fatigue of parts were.

Methods of Determining Wear in Engine Parts

At present there are many different methods of determining engine wear and engine life ; the suitability of using them in a given case is determined mainly by the degree of wear of the parts.

These methods are divided into 5 main types, after the classification proposed by M.M. Khrushchov:

1. micrometry, to determine the change in diameter or other linear dimensions, based on twofold measurement of the chosen part parameter, before and after wear and tear;
2. profilography, performed with a constant reference profile on the unworn part of the surface subjected to wear, or developed on the bottom of an artificially inscribed scratch;

3. determination of local linear wear by a method of impressions or a method of small cut-out holes, amounting to a determination of the changes in the dimensions of pits on the friction surface of a part;

4. overall method over the friction surface, which gives an estimate of the wear from the total weight loss or from the overall concentration of wear products in the oil;

5. overall method with respect to a service property, obtaining an estimate of wear from the variation of parameters taken as wear evaluation criteria.

The approximate methods which are applicable to motor vehicle engines can be reduced to 3 main groups: a) methods requiring removal of assemblies and parts for evaluation, b) methods giving a relative wear estimate, and c) methods giving a wear estimate with respect to service properties of the engine - which are, essentially, methods of evaluating the technological condition of an engine. In this section the first two classes of methods will be discussed.

The long-known and widely used methods of evaluating wear, micrometry and wear determination by the decrease in the weight of parts, belong to the first group of methods. These methods give poor representations for the initial period of factory running-in, but they give reliable measurements of wear accurate enough for practical purposes, of continuously operating parts.

However, neither of these methods gives a correct picture of the dynamics of wear. This can be explained by intensification of the wear after the dismantling which is necessary to carry out micrometry or weighing of the parts. Micrometry is subdivided into measurement either with or without a constant datum line from which the measurement is executed. In the first case it seems possible, with the aid of special indicating devices, to determine radial wear of cylinders or crankpins, which is very valuable in research. For this purpose, however, the application of the method of artificial datum lines which was worked out by M. M. Khrushchov and Ye. S. Berkovich is much preferable.

This method is performed on the UPOI-6 device and its modifications. It is based on the evaluation of wear from the change in the dimensions of holes cut into the friction surface. These devices enable the examination of wear in cylinders, piston rings, wrist pins, and crankpins. The method of artificial datum lines can be advantageously applied for short-time tests, characterized by low total wear, and for testing over extended operation of an engine. At the same time, study of the dynamics of wear, which requires opening up the engine, and, consequently, carrying out a new running-in of fitted assemblies after each dismantling, is fraught with the same kinds of errors as is ordinary micrometry.

In using the UPOI-6 device under laboratory conditions at the Gorki Motor Vehicle Plant, it was noted that the method of artifical datum points has particular advantage in the evaluation of wear in "wet" cylinder sleeves which have undergone deformation, in various models of the ZMZ engine. In laboratory research, the special device proposed by N.F. Strunnikov for determining radial wear is also used.

This is a lever-type contrivance with a measuring head. The device is centered with respect to a non-working part of the cylinder and the wear is measured from the imaginary vertical line off of the non-working region. The basic arrangement of the device is analogous to that of the "Kalibr" device for measurements within the factory. It is suitable for determining relative wear, but completely inapplicable for measuring cylinders which are highly deformed. In Fig. 7, characteristic wear diagrams are plotted for cylinders in GAZ-51 and GAZ-21 engines for 400-hr normal-operation test stand tests, representing micrometry, the method of artificial datum points, and the Strunnikov device.

Microprofilography belongs to the first group of methods of evaluating wear. The surfaces are gaged before and after engine operation, with subsequent superimposition of the profilograms with respect to the remaining unchanged lines of the depressions. This very approximate method is much more representative in determinations of initial wear during the short period of microgeometric running-in of fitted assemblies.

In the absence of microprofilographs of the "201" type and others, this method can be replaced by profilometry of the surface before and after short-time running-in. Possible errors involve nonuniformity of the microprofile over even small regions of the operating surface of the part, mainly waviness and macrononuniformities in friction pairs. The application of this method at high stages of wear does not give good results, since high stages of wear involve the formation of a new microprofile which depends little on the initial microgeometry.

The method of evaluating wear of round parts and openings by means of superimposition of macroprofilograms, which is widely used at the Gorki Motor Vehicle Plant, is among the methods which require dismantling the engine. This method was developed in the Central Scientific Research Laboratory for Engines, in conjunction with co-workers V. N. Komissarzhevskaya, L. A. May, and A. E. Isakov, of the NIITAvtoproma [Scientific Research Institute for Technology in the Automotive Industry]. It is based on the application of an MPG-3 macroprofilograph, designed by the NIITAvtoproma and built at the GAZ. The device is designed for measuring the external cylindrical shape of wrist pins, openings in piston bosses, internal surfaces of bushings at the small end of connecting rods, main and connecting rod journals on the crankshaft, and supporting bearings on the camshaft.

The device makes it possible to describe the macrogeometric deviations in parts, from the ideal form up to 0.1 mm, and with a magnification over the range of 1,000 to 10,000 times. It represents the macrodeformation of the studied surfaces via such parameters as ovality, angularity, coniformity, saddle-shapedness, barrel-shapedness, and waviness in a given spot, with respect to a vertical straight line and within a cross section. For correct superimposition of the macroprofilograms taken from the new and the worn part, impressions in the form of notches or holes are put ahead of time into the surfaces of new parts under study, and the subsequent superimposition of the profilograms is conducted with respect to these. The distance between the profilograms gives the value of the wear of the part on a relative scale. To give a visual representation of macrodeformations and the distribution of wear, the macroprofilograms are given in

Cylinder wear along diameter, microns

Region of Measurement of Cylinder

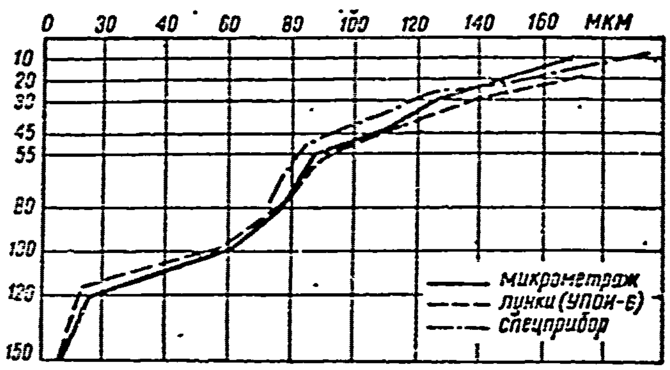


Fig. 7. Characteristic Wear Diagrams for Cylinders in GAZ-51 and GAZ-21 Engines After 400-Hr Tests According to GOST 491-55:
___ wear determined by micrometry; ---wear determined by (hole method) UPOI-6 device; -·- wear determined by Strunnikov's device

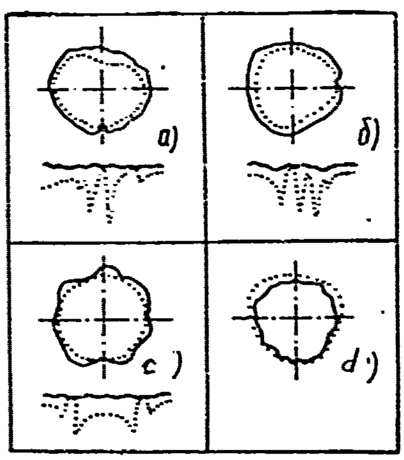


Fig. 8 Estimate of the character of the Distribution and Magnitude of Wear, with Respect to Out-of-Round and Non-Straightness, by Superposition of Macroprofilograms in:
a - main crankshaft journals; b - camshaft supporting journals; c - external surface of wrist pin; d - openings in piston below wrist pin

polar coordinates (Fig. 8). Currently, methods of reconversion of macroprofilograms have been developed at the Central Engine Laboratory at the GAC, by Engineer I.M. Tsoy; these make the process of converting the record to polar coordinates substantially less laborious. At the sam. Laboratory, A.E. Isakov has used a method of evaluating wear by planimetry of the areas formed by the initial and current profilograms.

A number of integral methods with respect to the friction surfaces -- enumerated below -- belong to a second group which gives a relative estimate of wear without dismantling the fitted assembly. Thus, a very promising method from the point of view of versatility is that of radioactive isotopes, or tracer atoms, which can emit energy in the form of electrically charged alpha and beta particles, and electromagnetic gamma rays, in the process of radioactive decay. Radioactive isotopes have been introduced to worn parts for subsequent evaluation of wear. The amount of wear in parts investigated in this way is found from the number of pulses recorded per unit time.

Various methods of activating parts are known; from the dissemination of these, systems of "tags" have resulted -- bits of electrochemical coating involving radioactive isotopes, and the introduction of radioactive isotopes into the metal when the parts are cast.

The potential feasibility of these methods rose particularly with the spread of the use of scintillation counters in place of Geiger counters; the former made it possible to sharply decrease the overall radioactivity of the parts under investigation, while retaining the necessary precision of measurement, and also to expand the list of usable radioactive isotopes. A differential method with radioactive indicators, developed at the Moscow Technical College imeni Bauman (Soviet Patent No. 184501, of May 20, 1965) is very accurate. This method is based on continuous or periodic measurement of a radioactive zone of the working friction surface of a part being tested, which part has been previously activated to a depth comparable to the amount of wear expected for the period of operation.

Of those methods applicable during any period of wear but most advantageous for research under conditions of running-in, one which has received particularly wide use is called, for short, "iron in oil" (GOST 5878-47 and 1955-45). The latter is based on the determination of the amount of wear products of the parts, mainly iron, which get into the oil.

Analysis of the oil samples may proceed by volumetric, gravimetric, calorimetric, or polarographic means, all of which are described in detail in the literature.

Knowing the amount of iron removed from the friction surfaces over several successive time intervals yields data on the growth in the amount of iron removed, and wear lines are constructed which characterize the dynamics of initial wear, or break-in, of the engine.

The transition of the wear line to a straight line having a definite slope marks the end of the initial microgeometric running-in, and the slope of the straight part of the line on a certain scale characterizes the intensity of wear of the basic friction surfaces. A high slope in the initial phase of running-in indicates the intensity of the process of microgeometric running-in, and the low slope in control tests of broken-in engines is evidence of the completion of this process in the break-in period.

This method, which was proposed by N.P. Voinov, was subsequently somewhat improved by S.V. Ventsel and the author of this book, in the area of estimating the influence of the lubricant system on the relation governing the growth in the concentration of iron in the oil, and in the area of simplifying means of taking the oil samples.

The above method of determining the optimal conditions of running-in required tests of 75 engines at the Gorki Moror Vehicle Plant. For direct observations of wear while the engine is operating, without taking oil samples, it was proposed that the Central Laboratory of the factory could use an ohmmeter, type F-57, which is capable of measuring resistances in the range 10^8 - 10^{14} ohm. The method is based on the fact that the electrical conductivity of the lubricating oil varies depending on the concentration of wear products in it. Since a polarograph is the best instrument for this type of measurement, one should regard a certain amount of non-correspondence of the wear lines as a result of errors in the new method. Such errors are unavoidable, as a result of the influence on the electrical conductivity of oil of temperature, various impurities, traces of water, the state of the surrounding medium -- variable in its physical and chemical properties -- and a number of other factors. Despite the approximate nature of this method, it can be recommended as a rough method for prior estimation of the overall wear of friction surfaces in engine parts.

In recent years, the estimating of wear with the aid of spectroanalysis has come to appear more promising. In this method, the content of impurities in oil samples from a definite volume taken from the lubricant system is found after burning in an electric arc and photographing the spectrum. From the results of processing these photographs, wear values for parts containing the different chemical elements are found.

The analysis and treatment of results in this method of testing are about as complex and lengthy as those in chemical analysis of oil samples, but the main advantage of this method is high accuracy. Other methods have been applied in research work for evaluating initial and settled wear with the aim of improving conditions of factory break-in and increasing the quality of engines produced. One such method is the determination of the degree of initial wear of the engine from the mechanical loss parameters.

The best of the known methods of determining these parameters for the purpose mentioned is the application of the engine torque measured by a beam electrodynamometer.

This method does not furnish high accuracy in determining absolute values of the mechanical losses, but when certain conditions are observed, it does give the change in mechanical losses during the process of running-in of the engine, with sufficient reliability for practical purposes. It is expedient, in order to judge the quality and necessary duration of running-in, to take control readings of mechanical power loss at a previously set rpm.

At the Gorky Motor Vehicle Plant, 35 engines were used in evaluation of experimental conditions of break-in by this method; the engines were previously chosen for average optimal values of microgeometry, clearances, etc. As a rough tactic for evaluating the duration of the initial engine break-in, the method of following the temperature of the crankcase oil at constant temperature of the cooling water may also be used.

Sharp fluctuations of oil temperature are evidence of the incompleteness of the process of initial running-in, and indicate the presence of local specific pressure highs, or even occasions of scoring on the friction surfaces of the parts. After the oil has reached the settled temperature, in the normal running-in of parts the temperature fluctuation of the oil should not be above 10°C.

Average values of oil temperature which characterize qualitative running-in of parts should be established experimentally for the various engine models, depending on the viscosity of the oil used for break-in.

In 1953, a simplified method of evaluating running-in according to the stabilization of the rpm in tests of idling engines was incorporated at the Central Engine Laboratory at the Motor Vehicle Plant. This method is based on "non-braking tests" of engines after major overhaul, which was rejected by V. Kazartsev and later proposed by the author of this book. The development of this method was based on investigations of 30 samples of various models of GAZ engines. In essence, it reduces to the plotting of curves of rpm variation at idle, in the presence of a limiting plate between the carburetor and the intake manifold

The diameter of the opening in the limiting plate is 18 - 20% of the diameter of the intake throat needed to assure normal feed conditions.

The evaluation of the breaking-in qualities is achieved by repeated testing of the engine. If the engine is completely broken in, then curves of the rpm of the initial and subsequent test coincide, which to an approximation represents equality of the internal friction losses.

If the curves do not coincide, this indicates that the chosen method of factory break-in of engines is imperfect. Another criterion for estimating initial wear can be the slope of the straight part of the rpm line (after warmup) with respect to the abscissa, and the difference in the initial rpm between the first and second tests of the engine. For this, the water and oil must be kept at comparable temperatures, and there must be complete

identity in the mixture composition adjustment and the spark advance angle. Application of this simplified method of evaluating initial wear of engines broken in differently permitted the factory to find the optimal conditions of factory break-in for GAZ-21 engines of the "Volga" automobile. It is also possible to estimate initial wear from oil burning and from gas blow-by.

In recent years, new methods of measuring wear have been expounded in the literature. Thus, scientists at the Saratovskiy Motor Vehicle and Highway Institute proposed a method of estimating wear of parts in the crankshaft-connecting rod and valve-camshaft mechanisms of an engine without dismantling the fitted assemblies; the method is based on a determination of relative clearances.

In application to the cylinder-piston assembly, this method reduces to the precise determination of the dimension of the scarf joint of the piston ring with the piston in the upper and lower stationary points before and after the testing of the engine. From the difference in the dimensions of the scarf joint, it is possible to judge increases in the conicity of the cylinder and wear of the ring over the time of the test. A special device, described in detail by the Saratovskiy scientist F.N. Avdon'kin, is used to determine the gap in the scarf joint.

A method analogous to this was developed for determining the gap in the fitted assembly consisting of a wrist pin and the bushing in the small end of the connecting rod, and also for determining bending in the valve tappet during engine operation, and gaps in the fitted pairs tappet-guide bushing and valve-bushing. Despite some degree of approximation in these methods, they have an undeniable attraction, particularly for vehicle repair enterprises and large enterprises involving vehicles.

At present in the Gorky Motor Vehicle Plant, development of additional methods is in progress, occasioned by the growing need for objective estimates of wear resistance of parts in new engine models.

Evaluation of the Technological Condition of Motor Vehicle Engines

The determination of the technological condition of engines is associated with one of the methods of estimating wear and life which was called by M.M. Khrushchov integral with respect to a service property. In this method, wear of a machine is evaluated from the variation of parameters taken as wear criteria.

For engines these parameters may be the lowering of the maximum effective power, increase in fuel consumption, oil burning, and blow-by of gases into the crankcase of the engine, a drop in the compression in the cylinders or in the vacuum in the intake manifold, a lowering of oil pressure in the oil headers, increasing gas pressure in the oil pan, and other parameters.

However, it may be erroneous to evaluate the state of the engine by one of these parameters without relating it to the others. Thus, an oil burning

rate not exceeding 3.5% of the gasoline consumption was taken as the current standard for the allowable rate for engines which have not undergone major overhaul and which are equipped with oil filters having replaceable filter elements. This approximately correct ratio does not, however, guarantee objective evaluation of the technological condition of the engine without dismantling it, because a very large number of factors affect fuel consumption and oil burning beside parts wear.

The vacuum in the intake manifold also does not give an accurate determination of the technological condition of the engine, since the amount of vacuum depends upon the condition of the air cleaner and the intake gas tube, the spark timing advance at idle, and other factors not involved with engine wear.

Determination of the technological condition of an engine from the pressure of gases in the crankcase involves extremely large errors because of the influence on that parameter of the throughput of the crankcase ventilation system, the loading and speed conditions of engine operation, the hermeticity of the crankcase seals, and other factors.

Neither does the compression meter have any particular claim to accuracy, in permitting conclusions about compression from the pressure in the cylinder at the end of the compression stroke, since lack of seal of the valve has a far greater effect on this parameter than cylinder wear. Thus, neither the parameters enumerated above nor other parameters can individually characterize the condition of an engine, or, if they do, it is with unacceptably large error. A more objective criterion may be the absolute value of oil burning in conjunction with other parameters, for example, with indices of gas blow-by into the crankcase of the engine under set operating conditions or vehicle speeds. Such data, for determining the possible service life of certain engine models up to major overhaul, have been published in the past. Thus, it was noted that the average rate of oil addition to compensate burning under service conditions of operation should not exceed, for highway driving at a speed of 35-40 km/hr, 1.2 l./100 km for the GAZ-51, and 1.5 l./100 km for the ZIS-150; gas pressure in the crankcase of the GAZ-51 engine running at full throttle should not be more than 80 torr, etc.

It was also noted that overhaul of the parts of the cylinder-piston group was necessary if the amount of gas reaching the crankcase under full load exceeded 120-130 l./min for ZIS-120 engines, 110 l./min for GAZ-51 engines, and 75-80 l./min for M-20 engines. However, until recently there have been no objective data on allowable values of indices of oil burning and gas blow-by for engines on vehicles which have not completed the warranty period. This often has lead to pointless pulling of the engine from the vehicle and to disassembly and replacement of run-in parts -- operations which were harmful to subsequent engine performance. With the aim of determining the possibility of evaluating the technological condition of an engine from the oil burning and gas blow-by, over 100 engines of models M-20, GAZ-51, GAZ-12, GAZ-21, and their modifications, with various degrees of wear of the basic parts friction surfaces, were subjected to an exhaustive study at the Central Scientific Research Laboratory for Engines at the Gorki Motor Vehicle Plant, between 1957 and 1962, under the direction of the author.

The task of the research reduced to determining the optimum ratio of oil burning to gas blow-by in the given engine models, since a deviation from this

ratio under tight-seal conditions in the crankcase and other seals characterizes upset of the normal technological condition of the engine.

Since oil burning and gas blow-by are influenced by a large number of varied factors, the study of these comprised the first stage of the investigation.

The operating conditions used in the test stand tests of the engines corresponded to the speeds of vehicle travel given in Table 5 for vehicles with direct driv. . The test stand tests were carried out on engines without limiting plates beyond the carburetors, for automobile engines, and also with tightened rpm governor springs, for truck engines. The length of each test set of operating conditions was 1 hr.

It should be mentioned that the test conditions were substantially more severe than service conditions of the engines, since a throttled-down carburetor is much more characteristic of highway operation. This artificial intensification of the severity of the engine operating conditions made it possible to obtain more pronounced results in comparative testing.

Table 5.

Conditions No.	Test stand test conditions of engines	Corresponding vehicle speeds, km/hr M-20, GAZ-69, GAZ-51	GAZ-12	GAZ-63	GAZ-21
1	Idle, 1500-2500 rpm		Idle		
2	Full load, throttle wide open, 2000 rpm	50	58	44	
3	Full load, throttle wide open, 3000 rpm	75	87	66	
4	Full load, throttle wide open, 3500 rpm	87	102	76	

Oil consumption during the test stand tests was determined after each run by weighing, to a precision of ±5 g, after decantation; in this, the necessity of draining all the oil from the oil system of the engine was taken into account. In highway tests the oil consumption by burning was determined from the addition of oil from a graduated flask.

From preliminary tests, the possible measurement error for each of the sets of conditions in the Table was determined; these were ±7, 10, 12, and ±15 g/hr, respectively. Increased scatter in the oil consumption index when the load and rpm are increased is explained by the influence of certain factors in the engine operation which vary along with these conditions. Such factors apparently include uneven wobbling and vibration of the piston rings and in particular their turning in the piston grooves, with a tendency to close the gaps in the scarf joints. The amount of exhaust gases passing through to the crankcase was measured with the

aid of a portable gas meter, type GKF-6, with a capacity of 6 m^3/hr, fastened to the oil inlet tube of the engine.

The unavoidable experimental and measurement errors in the research program were reduced by performing each test in triplicate on not less than 3-5 engines, with subsequent averaging of the results. Each of the studied engines was subjected to micrometry and to determination of the correlations of the separate parameters affecting oil burning and gas blow-by, and was made to conform to the tolerances indicated in the design drawings and in the engineering specifications.

In the research on the normal ratio of oil burning to gas blow-by for each engine model, and on the factors affecting the variation of this ratio, it was taken into account that extreme oil burning, as well as its complete absence, is distinctly contraindicated in normal operation of an automotive engine.

An excessively thick oil film on the upper piston ring causes "oiling" of the spark plugs and increased deposit formation, which promotes the growth of premature wear of cylinders and piston rings.

An insufficiently thick oil film can cause a rise in the rate of wear, since the oil film may proceed to break and the surfaces become dry, and dry friction may occur between the upper compression piston rings and the cylinder walls. The latter phenomenon is usually a result of high blow-by of gases through the piston rings, lowering engine efficiency and aggravating the severe temperature conditions of operation of the cylinder-piston ring pair. Also, the intensity of development of gaseous corrosion in the cylinders is related, to a substantial degree, to hot blow-by gases.

Evidently a certain constant oil consumption rate is an optimal condition for normal operation of the engine. The absolute value of this differs among the different engine models, and varies for a single model over the length of service. However, the gas blow-by should be a minimum; it is this parameter which to a significant degree characterizes the design perfection of a number of parts -- primarily, the piston rings -- along with the degree of engineering sophistication of their manufacture under production conditions.

As engine break-in proceeds, to a certain degree the microroughness of the friction surfaces of the parts is worn smooth, the initial macroirregularities of shape are reduced, the clearances in fitted parts are adjusted and stabilized, and consequently a certain relative constancy of the indices of oil burning, gas blow-by, and effective power comes about.

These indices, with the engine parts satisfying the requirements of the design drawings and the engineering specifications, are the starting point for subsequent evaluation of the technological condition of the engine.

In order to find the duration of running-in and the numerical values of the above indices, 3 sample engines of each of the models GAZ-20, GAZ-51, and GAZ-21 were subjected to 100-hr test stand tests. All the engines were first broken in at idle and under partial load for 9 hr, after which they were

subjected to testing at full load in 3-hr cycles in accordance with Sec. 58 of GOST 491-55.

The break-in and testing of all the engines was conducted with "Industrial-20" brand oil. The measurements of oil consumption, amount of gases passing through to the crankcase, and other parameters, were made in the engine tests under the sets of conditions listed in Table 5.

The total test was divided into 7 stages of 13 hours each, which, in combination with the previous running-in, corresponded to a 100-hr operation of the engine on the stand.

Fig. 9 shows the averages over all [sic] the engines of the indices of oil burning, blow-by of gases, and maximum power for the entire period of testing. Here the beginning of the relatively stable part of the curves of the studied parameters occurred after 55-75 hr of engine operation.

As break-in proceeded the average rate of oil consumption in the M-20, GAZ-51, and GAZ-21 decreased in comparison with the initial rate from 116 to 54, from 260 to 170, and from 100 to 50 g/hr, respectively; and blow-by of gases rose from 26 to 27, from 36 to 42, and from 27 to 29 l./min, respectively.

In subsequent 400-hr tests of GAZ-21 engines under the conditions of GOST 491-55 it was found that after 300 hr of operation the oil burning again increases somewhat.

A substantial increase in the indices of oil consumption and, to a lesser degree, gas blow-by was observed under increased loading and increased rpm of the engine.

The latter is connected with increased tendency to accumulate oil underneath the rings and with increased gas pressure, as well as with the rise of deformation of the cylinders and vibration of the piston rings. During engine operation under load with the carburetor throttled down, the rate of oil consumption decreases a little.

The inverse relation between oil burning and gas blow-by found in the tests can be explained either by the formation of a condensed elastic oil mass underneath the upper rings which prevents penetration of gases into the crankcase, or by oil being blown through along with the blow-by gases under pressure.

As running-in of the friction surfaces of the engine parts proceeds, the rate of oil consumption decreases to an identifiable medium value, while the gas blow-by increases once again and then later also evens off.

It can be logically assumed that this shape of the curve of blow-by of gases is connected with the closing of the scarf joints of the piston rings during the operation of the engine.

In the longer tests viscosity was found to have some effect on the rate of oil consumption. To determine this effect in GAZ-M-20 engines comparative tests

were performed with "Industrial-20" and "Industrial-50" oils, the viscosity of which decreases to 1.3 and 1.6, respectively, when temperature is raised from 50 to 100°C (Fig. 10).

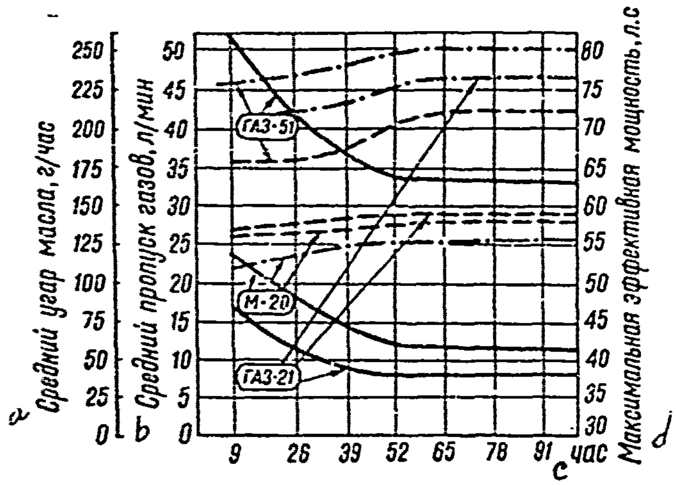


Fig. 9. Average Engine Indices of Oil Burning, Gas Blow-By, and Maximum Power, as Functions of Duration of Test: —— oil burning; --- blow-by of gases; -·- effective power.

Key: a = ave. oil burning, g/hr; b = ave. blow-by of gases, l./min; c = hr; d = max. effective power, hp.

The tests showed that the engines consume low-viscosity oil at a rate 15-20% higher than machine oil. This is connected with the superior pumpability and the penetrability of low-viscosity oil into the open spaces in parts linkages of the engine.

In the studies it was found that the intensity of lubrication of the parts of the cylinder-piston group has no effect on the rate of oil consumption; this was shown in tests of engines with varying amounts of oil flowing into the crankcase, in which oil pressure was varied by adjusting the reduction valve in the oil pump in combination with the covering of oil passages, to achieve additional lubrication of the cylinders at lower ends of the connecting rods.

The studies showed that regardless of how much oil collects underneath the piston rings oil penetration into the combustion chamber through the cylinder-piston group depends mainly on the tightness of the seal of the piston rings and the degree to which they have been run-in to fit the cylinders. On the other hand, the amount of oil in the valve space of the engine has a significant effect on oil burning; this was shown from comparative test stand tests on M-20 engines with and without oil deflectors in the valve space.

These data were confirmed in road tests of the "Pobeda" automobile. In these tests the average specific oil consumption of M-20 engines with oil deflectors did not exceed 56 g/100 vehicle km, while without oil deflectors it reached 108g/100 km.

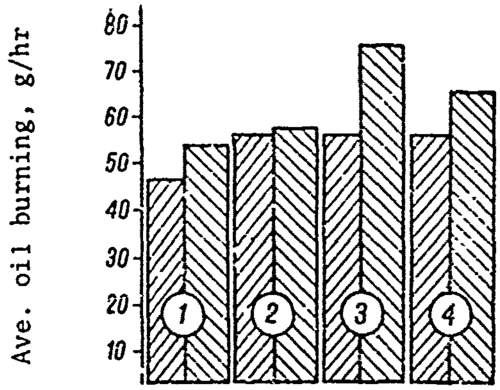


Fig. 10. Influence of Certain Factors on Oil Burning in 4-Cylinder GAZ Engines:

1 -- viscosity of oil used: VU_{50} = 6; VU_{50} = 3;

2 -- closing off of passages in connecting rods:

passages closed; passages open (for supplementary lubrication of the cylinders);

3 -- presence of oil deflectors in the valve space:

with oil deflectors; without oil deflectors;

4 -- cross section of oil passages in pistons:

openings unclogged; openings clogged.

The above is evidence of the substantial effect the valves have, via their sucking action as they move in the guide bushings, on the amount of oil consumed by the engine. The process is aggravated by the intense suction of gases under existing systems of crankcase ventilation. The effect of crankcase ventilation and a number of other design factors, including clearances in fitted assemblies, are topics discussed elsewhere in this book.

These parameters and factors, acting separately and in concert upon oil consumption and gas blow-by, do so in addition to other, operational factors, under actual conditions of engine service. Among these operational factors are the quality of the lubricating materials in the fuel, the absence of patterns of wear on the friction surfaces of the parts of the cylinder-piston group as a result of differences in operating conditions, resin formation and tarring of the oil control rings and grooves in the piston, etc.

Actually, in the case of reverse flow of excess oil, only constricting the openings in the grooves for the oil-clearing rings in the piston will increase the oil consumption rate. The total passage cross section of these 13 openings of diameter 3 mm each is 31 mm^2; and in combination with the radial channel to the other side of the piston the area is 147 mm^2. By blocking 6 of the openings in the piston grooves, thus decreasing the drainage cross section to 49 mm^2,

the effect on oil consumption of decreased drainage area was determined.

Also, in the course of the tests of a number of engines, the strongly negative effect on performance of the practice in many motor vehicle and vehicle repair enterprises of overhauling engines after running-in and break-in was noted. Such overhauling, i.e. opening the engines after inspection and testing of the friction surfaces of the parts, subsequently obligates a new process of running-in and increases the indices of oil burning and gas blow-by.

Since oil burning and gas blow-by are indices of the overall technological condition of the engine, the general character of the relation between them at various degrees of wear of the engine is of interest.

In Table 6 the results of evaluation of the technological condition of GAZ-21 engines after their service on vehicles are given.

The technological condition of these engines was evaluated from data on speed and load characteristics and from the results of micrometry of parts after determining the oil burning and gas blow-by.

Table 6.

Service mileage of vehicle, 10^3km	Effective power, hp	Fuel consumption, g + effective hp	Characteristic properties of engine condition, from data of inspection and micrometry	Ave. oil burning, g/hr	Ave. gas blow-by, liter/min
15	72	220	No notations.	65	29
30	73	215	No notations.	70	28
44	71	215	Rubber packing on valves eaten away.	90	30
47	68	230	Sticking of piston rings.	120	40
50	72	220	No notations.	60	30
53	71	210	No notations.	70	30
83	68	235	Deformation of sleeves to the extent of 1 mm, and sticking of piston rings.	150	35

It follows from Table 6 that when GAZ-21 engines are in good technological condition, the maximum oil burning and gas blow-by do not exceed 70 g/hr and 30 l./min, respectively.

In Table 7 the minimum and maximum values of oil burning and gas blow-by for 30 engines of types M-20, GAZ-51, GAZ-12, and GAZ-21 in good technological condition are given; these values were determined by taking the speed characteristics, by micrometry, and by visual inspection of the engine parts. The indices of oil burning and gas blow-by were determined under laboratory conditions

with closed crankcase ventilation systems, under the sets of conditions of Table 5, with the engines using "Industrial-50" oil.

Oil consumption tests were conducted on the same engine models under highway testing with various road conditions and varied vehicle speeds. The service mileage on the vehicles at the time was from 3 to 25×10^3 km. The tests yielded the following average values of oil consumption rate due to burning: for M-20 engines, 42-95 g/100 km; for GAZ-51 engines, 120-180 g/100 km; for GAZ-12, 130-200 g/100 km; and for GAZ-21, 35-80 g/100 km.

In subsequent testing the technological condition of all these engines was found to be completely satisfactory: the maximum cylinder wear in them did not exceed 0.07 mm, and the maximum clearance in the scarf joints of the piston rings was not above 1.5 mm.

It should be noted that it did not seem possible in the research to establish a regular relationship between the high or low values of the indices of oil consumption from Table 7 and the state of wear of the cylinders and piston rings, in the range of values given. Thus, when premature wear of the cylinders in two M-20 engines and three GAZ-12 engines was artificially induced to the extent of up to 0.05 - 0.07 mm, the average rate of oil consumption, under the previously adopted sets of conditions, practically did not change in relation to the initial indices, not exceeding 75 - [sic] 180 g/hr, respectively.

Table 7.

Parameter studied	Engine model GAZ-20 GAZ-69	GAZ-51 GAZ-63	GAZ-12	GAZ-21
Oil burning, g/hr	30 - 90	120 - 180	130 - 200	25 - 75
Oil burning, g/100 km	40 - 120	130 - 190	150 - 230	30 - 110
Gas blow-by, l./min	20 - 30	40 - 80	45 - 52	20 - 30

The values of gas blow-by around the piston rings here, however, were at the upper limit of the values in Table 7, reaching 30 and 50 l./min, respectively.

Extreme wear of cylinders and piston rings was accompanied by a sharp rise in the average indices of oil burning, reaching 300-350 g/100 km on M-20 engines, and 500 g/100 km on GAZ-12 engines, with cylinder wear up to 0.1 mm.

Therefore, the evaluation of the technological condition of an engine may be based on the rate of oil consumption only in conjunction with the indices of gas blow-by around the piston rings.

Even then, such a method of evaluation cannot be assumed to be error-free, since a large number of initial parameters over and above the new factors involved in the operating conditions affect the indices of oil burning and gas blow-by. Thus, decrease of the open cross section of the openings in the lower piston grooves underneath the piston rings due to resinification can increase the average oil consumption rate by 10-15%; this rises substantially in the event of attrition of the guide bushings and valves as a result of sticking of the piston

rings, etc.

Thus, the values of the indices of oil burning and gas blow-by given in Table 7 can be taken as approximate criteria for evaluating the overall technological condition of M-20, GAZ-51, GAZ-12, and GAZ-21 engines and their various modifications. Since under actual service conditions an engine mainly operates with the carburetor throttled down, the actual indices of oil burning and gas blow-by are usually much lower than the permissible values given.

High oil consumption in the initial period of service of an engine may arise as a result of the process of running-in of the parts being drawn out.

The stated method of evaluating the technological condition of motor vehicle engines obviously does not exhaust all possibilities in this direction; however, despite its approximate nature, it is admittedly the most objective and efficient method.

Other existing methods may be used in conjunction with evaluation from oil burning and gas blow-by. For example, the method of determining the technological condition of an engine from the drop in effective power and the rise in fuel consumption -- while it is very suitable in the period of the onset of progressive, or catastrophic, wear -- without simultaneous use of the method of evaluation from oil burning and gas blow-by can lead to erroneous conclusions. Errors are likely because a drop in power and an increase in fuel consumption are possible not only as a result of wear and tear of parts and fitted assemblies, but also as a result of defects in the carburetor and distributor, and for other reasons.

In the practice of vehicle operation, very frequently the condition of the engine is evaluated according to the noise during operation. This is a subjective method, due to the individual talents of the different practitioners. On the other hand, the way acoustic equipment is being invented, great promise is afforded in this direction.

Chapter III

Characteristic Features of Operation and Wear of Engines

Heat Straining of Automotive Engine Parts

The problem of increasing motor vehicle engine life cannot be solved in isolation from a number of questions connected with thermal conditions of the engines and heat straining of the main parts. The number of investigations of various types which have been carried out in this area is extremely large. However, because there is neither a perfected methodology nor sufficiently accurate apparatus, generalization of these efforts presents appreciable difficulties and does not always give completely objective results.

The complexity of this problem has been aggravated by the fact that until the present there have been no sufficiently reliable methods of calculation and theoretical investigation of heat transfer and thermal straining of parts.

Heat straining of an engine is governed by the heat fluxes through its parts. It depends on the quantity of heat produced, distribution, and the amount of heat conducted away from the parts into the cooling medium. In the present work, only that part of the question is dealt with which involves the distribution of heat fluxes over thermally stressed surfaces of certain crucial engine parts.

In recent years a number of research reports have been devoted to this question, making it possible to ascertain the relation between the thermal conditions in various engine models and the coefficient of excess air, the spark advance angle, and other factors. Thus, it was determined that the character of the temperature variation in pistons and valves as a function of the coefficient of excess air α is the same for all engines, and the maximum temperature at full loading corresponds to that mixture composition which guarantees the highest rate of combustion and the highest average indicated pressure.

It was also determined that the lowest parts temperature corresponds -- other conditions being equal -- to the most efficient spark advance; that the temperature of the cylinder heads and pistons increases linearly with increasing speed, etc.

The average working temperatures of the separate parts were determined: cylinder walls, up to 100°C; intake valves, 150 - 250°; exhaust valves, 600 - 840°; cast iron pistons, over 400°; aluminum pistons, around 250°; and electronic sic , around 220°C.

Research reports published in recent years dealing with thermal straining of motor vehicle engine parts, performed at the Scientific Research Institute of Motor Vehicles and Motors of the NAMI [Central Scientific Research institute of Motor Vehicles and Motors], are of especial interest.

The variety of experimental conditions and means of measuring temperature often causes substantial disagreement in the results, other conditions being equal, and thus does not always provide a sufficient background for theoretical generalization. Accordingly, any additional information in this area is both useful and necessary for domestic motor vehicle engine production.

The above served as the motivation for the mentioned studies of operating temperatures of cylinder walls, pistons, main crankshaft bearings, camshaft bearings, valves, and valve guide bushings of various models of engines from the Gorki Motor Vehicle Plant ("GAZ") and the Zavolzhsk Motor Plant. This work was carried out at the Central Scientific Research Laboratory for Engines at the GAZ by the author, in collaboration with the engineer A. P. Yegorova.

It is well known that in engines with water cooling the maximum temperature of the cylinder surface is in rare cases 200°C, but the nonuniformity of the temperature field in these cases is very high. Thus, in measuring the operating temperature of cylinders of GAZ-51 engines, a sharp increase in temperature in the region opposite the valves was recorded. At full loading and 2500 rpm, it reached 130 - 140°C; and in the diametrically opposite direction, 80 - 100°C. In the lower part of the cylinders the temperature under the same conditions was between 70° and 115°C. A substantially less nonuniform temperature field was noted in "wet' cylinder sleeves of GAZ-21 engines on "Volga" automobiles. Thus, the investigator B. A. Vzorov found that the maximum temperature in the upper region of the sleeve of the first cylinder, with a Nirezist insert, is 180°C, with a temperature fluctuation around the sleeve of not over 10°C.

In the same part of the sleeve of the second cylinder on the side of the intake manifold the temperature reached 205°C, which is explained by the formation of a vapor pocket. The vertical temperature difference along the sleeve between the two stationary points of the upper piston ring was around 30°C. These studies of temperature variation used cylinder sleeves of two engine modifications: GAZ-21A with compression ratio 6.7:1 and with a gasoline octane number of 70; and GAZ-21D with compression ratio 7.5:1 and octane number not below 90.

The method of measurement amounted to recording the temperature with Chromel-Copel thermocouples with wire diameter 0.6 mm. Temperature was measured on all cylinders from the intake manifold side and the opposite side at distances of 13.65 and 105 mm from the upper flat surface of the engine block. The hot junction of each thermocouple was installed at a distance of 0.5 to 1.0 mm from the friction surface and made fast by a method of acidless soldering (Fig. 11).

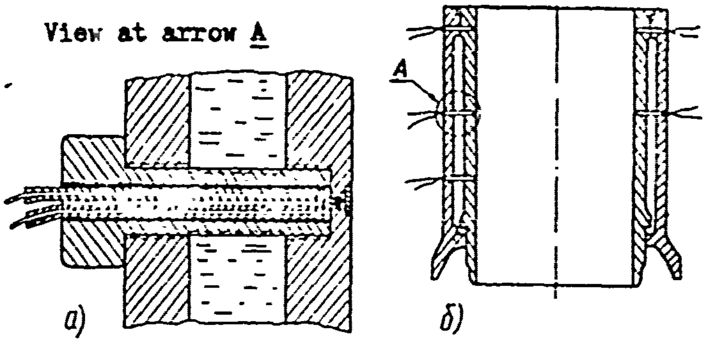


Fig. 11. Arrangement of Thermocouples:
a -- attachment and sealing of thermocouples in "wet" cylinder sleeves in GAZ-21 engine;
b -- arrangement of thermocouples along height of cylinder.

In the recording of the temperature characteristics a portable type PP potentiometer was used. During the tests the oil temperature in the crankcase was held within the limits of 70 and 95°C, and the outlet water between 75 and 80°. In studying the influence of operating conditions on the temperature of the cylinder sleeves the temperature characteristics were taken at idle and also with the engine working at full load at 1500, 2000, 2500, 3000, and 3500 rpm. The curves (Fig. 12) indicate that the loading has the greatest effect on the increase of temperature in cylinder sleeves. A relatively even distribution of temperature among the several cylinders was noted in the tests, with maximum temperatures around 160°C in the upper zones of the cylinder sleeves, in which respect the GAZ-21 engine models compare favorably to the flathead GAZ models.

Significant advantages were noted also in the uniformity of the temperature distribution around and vertically along the sleeves. Thus, in operating the GAZ-21 engine at full load and 3500 rpm the maximum temperature variation around the sleeve was not over 28°C, and vertically not over 65°C. From the studies the effect on cylinder temperature of spark advance angle, increased compression ratio, and operation of the engine with knocking were determined. In the latter case a sharp increase in temperature in the upper region of the cylinders was noted.

The study of the operating temperature field in the piston has acquired particular significance in recent years in connection with the increased frequency of cases of piston burn-through in contemporary high-performance vehicle engines. The greatest number of measurements of temperature in pistons has been made with the aid of a multipronged contact current tap of the NAMI design, which gives a temperature reading about 10% higher than with a sliding contact current tap.

Generalization of the studies carried out in this direction indicated that:

a) in present-day carbureted engines with water cooling the operating temperature at the center of the piston head is within the limits of 250 - 300°C, at the edge of the piston head 220 - 260°C, in the region below the piston rings 130 - 150°C, and in the lower part of the piston skirt 100 - 110°C;

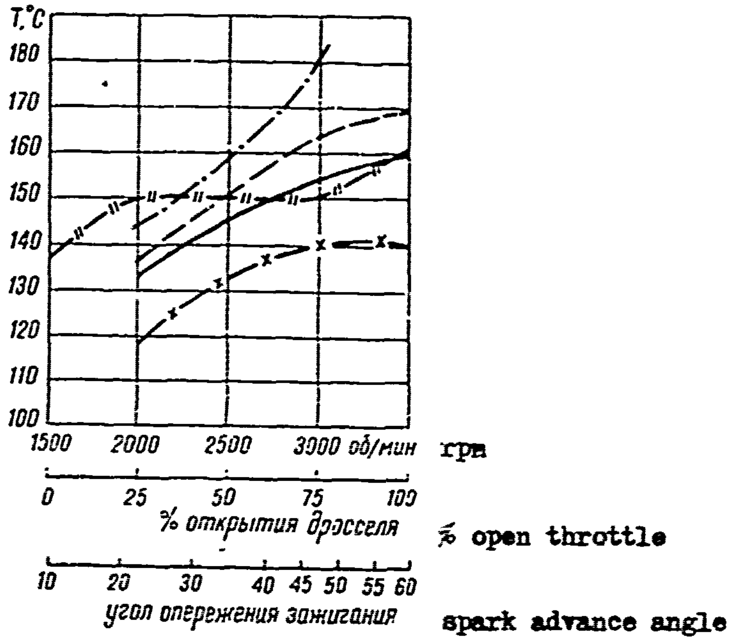


Fig. 12. Effect of RPM's, Loading, and Spark Advance Angle on Temperature of Cylinder Sleeves in GAZ-21A and GAZ-21D Engines, under Various Conditions of Operation: -•- idling; -x- heavy load put on GAZ-21A engine at n = 2,000 rpm; -"- varying spark advance angle on GAZ-21D engine, at n=2,500 rpm; —GAZ-21A engine at full load; --- GAZ-21D engine at full load; -•- GAZ-21D engine with knocking.

b) for cast iron pistons in these same engine types the temperature rises in the center of the piston head by about 100°C, at the edge of the piston head by 40 - 50°C, and elsewhere by 5 - 10°C;
c) in air-cooled carburetor engines the temperature of all zones of the piston is substantially higher than in water-cooled engines; thus, the temperature of the center of the piston head for pistons made of aluminum alloys reaches 330 - 350°C, and for pistons made of cast iron 420 - 430°C;
d) for diesels with pistons made of aluminum alloys the temperature at the center of the piston head, with direct fuel injection, is 250-280°, at the edge of the piston head 180 - 200°C, in the area below the piston rings 130 - 140°C, and in the lower part of the skirt 100 - 110°C. With the prechamber design, the temperature of the pistons is substantially higher; in the center of the piston head it reaches 380 - 400°C;
e) in diesels with cast iron pistons even higher temperatures occur; with prechamber heads, these reach 450°C in the center of the working face of the piston and 390 - 400°C at the edge.

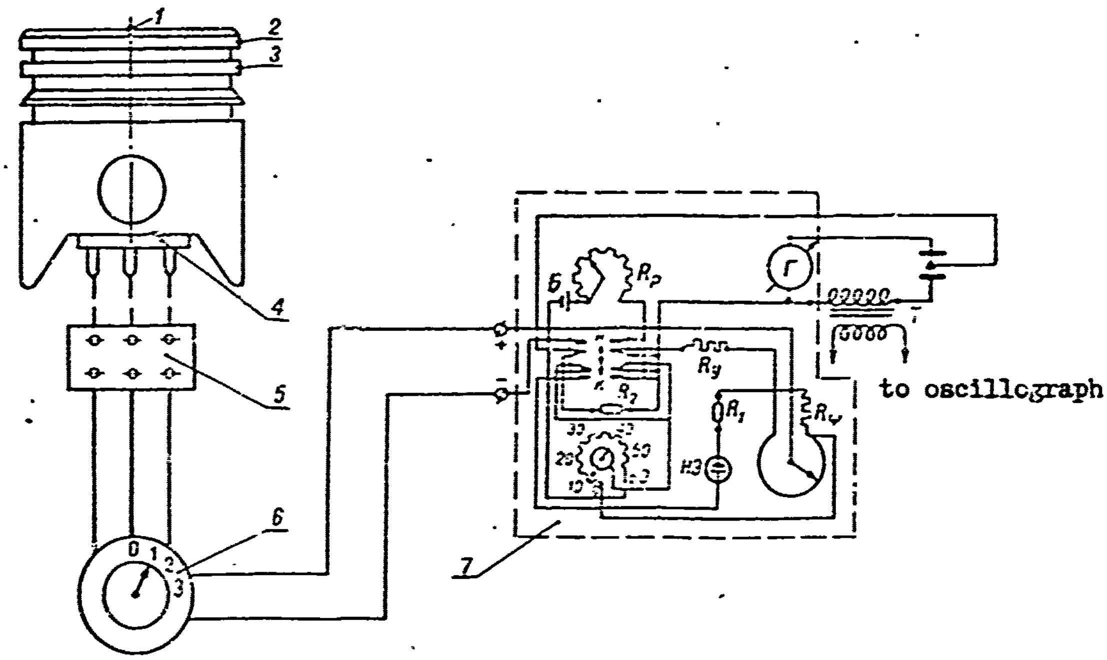


Fig. 13. Diagram of Multipronged Current Tap with Type PP Compensating Potentiometer:
1,2,3 -- arrangement of hot thermocouple junctions in piston; 4 -- sliding contact current tap shoe, fastened to piston; 5 -- collecting shoe, fastened to engine block; 6 -- thermocouple switch; 7 -- compensating device.

The main experimental part of this stage of research was to be the study of thermal straining of the pistons of GAZ-21A and GAZ-21D engines. Spring contact current taps designed by the Central Scientific Research Institute of Diesels [TsNIDI], sliding contact current taps, and a multipronged contact device developed at the NAMI were tested with the aim of finding the best method of temperature measurement. The latter device turned out to be the most reliable.

The temperature of the piston was recorded with Chromel-Copel thermocouples with wire diameter 0.3 mm. The hot junctions of the thermocouples were installed 0.5 to 1.0 mm from the surface. The piston contact in this was made from a thermoelectrode material in the form of a sharp pin which slid along the line of the coils of a winding as the piston approached "bottom dead center".

The design of the device also involves current-tap and collecting textolite shoes, the first of which is installed in the piston bosses, and the second in the cylinder block.

The multipronged current tap yields a discontinuous current in the thermocouple circuit. An electronic oscillograph, displaying the amplitudes of the current pulses, was used as a null indicator.

The main objects of study were GAZ-21A and GAZ-21D engines with K-22 and K-105 carburetors. During the tests the temperatures of the crankcase oil and

the water leaving the engine were maintained within the limits of 70 - 95°C and 75 - 80°C, respectively.

The temperature characteristics of engines at the center and at the edge of the piston head are plotted in Fig. 14. It was found that under normal burning of the fuel mixture, the form of the temperature increase of the piston follows the curve of effective power, and like it has a bending point at 3500 crankshaft rpm. The maximum temperature for all modifications of the GAZ-21 engine in the center of the piston head was not over 300°C, at the edge of the piston head it was about 250 - 275°C, underneath the upper compression ring 190 - 220°C, and on the piston skirt around 100°C. These data from the center and edge of the piston head differ little from the results of tests carried out at the NAMI.

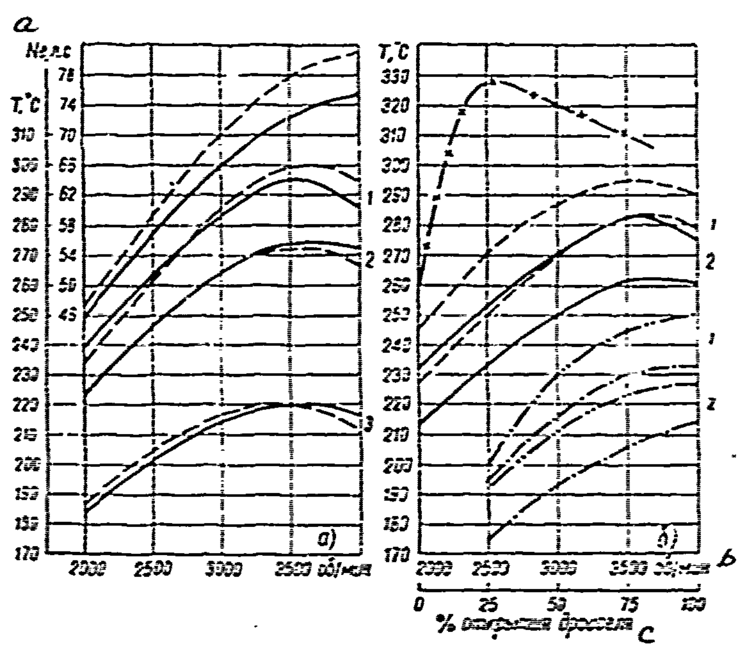


Fig. 14. Effect of Various Factors and Parameters on Piston Temperature:
a -- effect of rpm, power output, and compression ratio on piston temperature in GAZ-21 and GAZ-21D engines:
1,2,3 -- temperature measured at center of working face of piston, at edge of working face, and under 2nd compression ring, respectively:
— GAZ-21A [sic] engine; --- GAZ-21D engine
b -- effect of spark advance angle, knocking, and increased load at constant rpm, on piston temperature in GAZ-21A engine:
— normal engine operation; --- spark advanced by 15°; -x- strong knocking; -·- increased load; -··- increased load plus spark advanced by 15°.
Key: a = Effective hp; b = rpm; c = % of open throttle.

In the tests a sharp increase of temperature was noted under knocking conditions of mixture combustion. The temperature of the center of the piston head under these conditions reached 320 - 330°C at 2500 - 3000 rpm. Substantial temperature increases in the piston were also recorded with progressive opening of the throttle valve and with increases in the spark advance angle in the tests. These studies confirmed that the burn-through of pistons in GAZ-21D engines which has occurred in the past is connected with knocking in the burning mixture at compression ratios inappropriate to the octane number of the gasolines used.

In this, under the effect of high temperatures, the start of burn-through of the pistons precedes appreciable lowering of the hardness of the copper-silicon alloy used in the pistons. Special high-silicon Silumin, containing 11-13% Si, was introduced in the production process as a more heat-resistant and hard alloy for pistons.

The temperature field in the bearings of the crankshaft has interested researchers for many years now, from the point of view of seeking ways of prolonging the service time of inserts and increasing their resistance to the spalling and chipping of the working layer. Thus, according to research data, the lowering of the temperature of bearings from 160 to 100°C increases the operating life of inserts without the appearance of cracks by a factor of over 7 times.

The current research into temperature fields of bearings is a continuation of research carried out at the Moscow Technical College imeni Bauman. Comparative studies were carried out on 2 standard GAZ-20 and GAZ-21 engines. The temperatures of the inserts were measured with Chromel-Copel thermocouples with the heads of the junctions 2 mm in diameter. The thermocouples were 0.5 mm away from the friction surfaces, and were arranged as shown in Fig. 15.

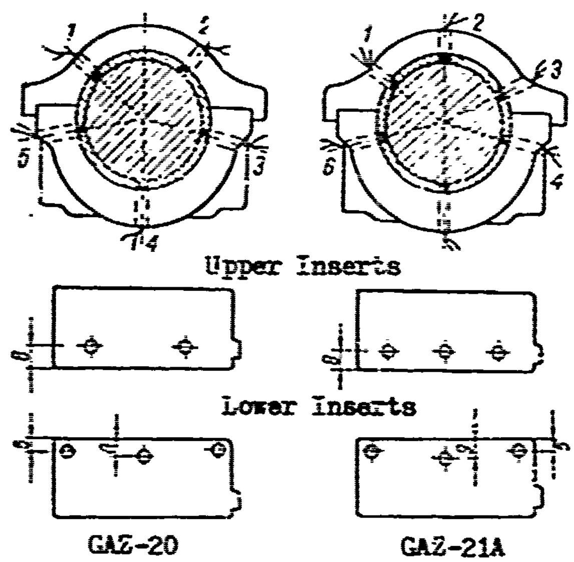


Fig. 15. Arrangement of Thermocouples for Measuring Temperature of Main Crankshaft Bearing Inserts in GAZ-20 and GAZ-21A Engines.

The thermocouples were fastened in and sealed by the method of acidless soldering, with tin solder. The thermocouple leads from the main bearings were brought out through the juncture between the engine block and the oil pan.

The temperature of the oil going to the main bearings was measured by a thermocouple which was mounted in the oil passage. The temperature of the middle layers of oil in the oil pan was also determined with a thermocouple. All the thermocouples were connected to a PMT-20 selector switch, and further to a MPB-46 millivoltmeter.

The temperature characteristics were taken at idle and under 100% load over a wide rpm range. When the testing was under a load the temperature of the cooling water at 2000 rpm in the M-20 engine was within the limits of 70 - 75°C, and in the GAZ-21A engine within 68 - 70°C; and the oil temperatures in the oil pans did not exceed 80 - 95°C [sic], respectively. This difference in water and oil temperatures is connected with design features of the engine models which were tested. In Fig. 16 the temperature distribution along the diameter [sic] of the 1st main bearings, which reflects the influence of rpm, loading, and other parameters including oil viscosity, is plotted. The curves indicate that the speed has the greatest effect on increasing the temperature of the bearings. In this regard, under the test conditions a high temperature in the main bearings of the GAZ-21 engine was noted in comparison with that of the GAZ-20.

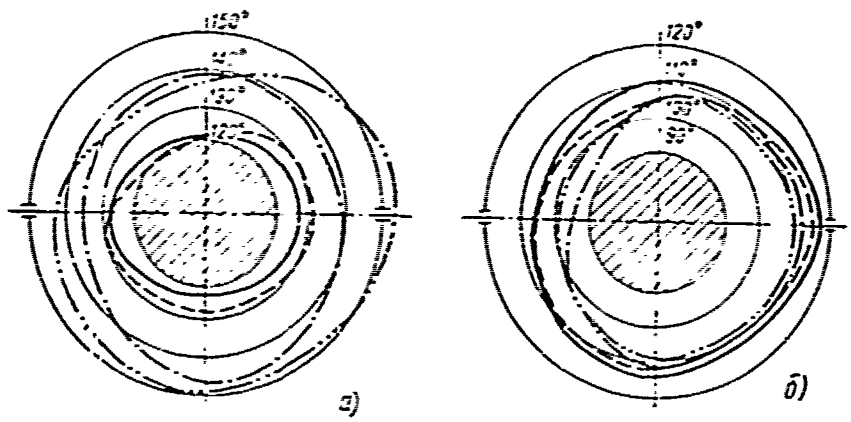


Fig. 16. Distribution of Temperatures along the Diameter [sic] of the Bearings, Relative to Various Factors and Parameters:
a -- effect of engine rpm and loading on temperature of main bearings:
—— at idle, GAZ-M20 engine; --- 100% load, GAZ-M20 engine;
-•- at idle, GAZ-21 engine; -••- 100% load, GAZ-21 engine;
b -- effect of oil pressure and viscosity, and of graphite additive, on temperature of main bearings:
—— oil with a VU_{50} viscosity of 6; --- oil with a VU_{50} viscosity of 3; -•- 2% graphite additive; -••- oil pressure increased by 1 kg/cm^2.

Thus, the maximum temperature in the GAZ-21 engine at 100% load and 3500 rpm was over 150°C, while in the GAZ-20 engine the temperature of the bearings did not exceed 130°C. In addition, the temperature is more evenly distributed circumferentially around the bearings in the GAZ-20 engine than in the GAZ-21; this is explained by the high stability of the operating clearances in the bearings of the former. By analysis of the temperature characteristics the zones of maximum overheating, located on the walls of the inserts (on the right side in the direction of rotation of the crankshaft) and in the lower space, were found. The observed 7 - 10°C temperature increase at the joints of the inserts in the GAZ-21 engine, and 4°C in the GAZ-20 engine is explained by the phenomenon of deformation of the main bearing covers.

The 4 - 5°C temperature difference between upper and lower inserts is evidently a consequence of binding of the friction surfaces of the lower insert and the crankshaft journal. Despite the uniformity of the temperature of the oil entering the oil headers of the engine, the temperature of the oil going to different bearings differs. In the M-20 engine the highest temperature oil was that entering the second and third bearings; in the GAZ-21A, that entering the third bearing. Tests showed that there is a rather large temperature increase when engines are operated on high viscosity oil. This is evidence that low viscosity oil has better cooling properties. A 2% addition of colloidal graphite preparation to "Industrial-50" oil has an effect on the temperature of the bearings. The presence of this preparation in the oil substantially lowers the temperature. In addition, the positive effect of increased oil pressure in the engine system was noted.

With the aim of making a rough determination of the real operating temperature conditions in the main bearings of the engine, temperature characteristics were taken under conditions of vehicle service, with throttle variation at 2000 rpm. These tests showed that the temperature of the bearings increases as the throttle valve is opened, the constancy of the rpm notwithstanding.

In addition, the temperature of the bearings was measured during engine operation under a combination of conditions with various angles of throttle opening, at idle and under loads, with rpm varying over the range of 1500 - 3500. In these tests the maximum temperature of the bearings did not exceed 93°C in either engine. From a determination of bearing temperature arising directly from turning friction it was established that, other things being equal, this temperature is nearly the same as that in engines operating on gasoline.

The studies showed that, under identical sets of test conditions, the temperature of bearings and crankcase oil in a GAZ-21 engine is 10 - 15°C higher at low rpm and 20 - 30°C at high rpm, in comparison to an M-20 engine. Additional studies also showed that heat straining of the camshaft bearings in a GAZ-21 engine is high in comparison to a GAZ-20. It is well known that with increasing temperature babbit substantially decreases in hardness and suffers deterioration of its mechanical properties. Thus, when temperature increases from 100° to 150°C the hardness of babbit falls from Hb [Brinell] = 8.93 to Hb = 4.92. These data, in combination with previously given information, indicated that it is necessary to use new materials for inserts, and that new means must be sought of lowering the operating temperature of bearings. The first problem was solved in Soviet motor vehicle plants by changing from the tellurium babbits used formerly

to the antimony alloy SOS-6-6, which is more resistant to fatigue deformation and the action of high temperature. The second problem has not yet been solved, but the research which has been accomplished permits the recommendation that the oil pressure be raised in the engine system and that colloidal graphite preparation be added to the oil. Lowering the viscosity of the oil, which has a positive effect on the process of running-in, can be recommended only to the point of accumulation of perceptible wear in the fitted parts of the engine.

The exhaust valves are another part of the vehicle engine which is heavily loaded thermally: they operate subject to active corrosive media in the exhaust gases, and high frequency pulsating loads. In service the stems and heads of the valves become covered with carbon deposits, the thermal conductivity of which is 30 - 50 times less than that of cast iron or steel, thus aggravating the already severe conditions of operation of these parts.

There have been a large number of research reports dealing with the measurement and analysis of operating temperatures of exhaust valves. From the generalized results of research, the temperature of exhaust valves in truck engines with compression ignition lies within the limits of 760 - 800°C, in high power carbureted truck engines 800 - 840°C, and in automobile engines 600 - 750°C. For a 700°C maximum temperature in the center of the valve head of an automobile engine, away from the outer surface this decreases to 630°, at the seat to 620°, in the radius zone from the head to the stem it again rises to 700°, and in the upper part of the stem it is 560°C.

In a number of studies the dependence of valve temperature on a number of factors and parameters has been established: these include the coefficient of excess air, the compression ratio, rpm, loading, etc.

There are several well known methods of measuring valve temperature, but the most precise is the use of thermocouples. In the present research a 2-wire thermocouple was used which allowed measuring the temperature in the center of the valve head (Fig. 17). The thermocouple was made of Chromel and Alumel wires of diameter 0.5 mm, and passed through an opening drilled completely through the valve stem and capped off at the valve head end. The thermoelectrodes were insulated from the body of the valve by a double-channel porcelain tube 2.7 mm in diameter. The hot junction of the thermocouple was protected by a metal cup. The wire from the thermocouple passed through a hole in the valve wall into the valve compartment, and further to the terminal of the recording device, a type PP compensating potentiometer.

All the tests were conducted on GAZ-21D, GAZ-51, and GAZ-13 engines. The temperature characteristics of the GAZ-21D engine with a compression ratio of 7.5:1 and a maximum power of 76 hp were taken on each cylinder alternately, using one thermocouple, at full load and at rpm varied from 2000 to 4000 at intervals of 500 rpm. Gasoline with an octane number of 90 was used. The results of the tests, given in Fig. 18, showed that as rpm increases at full load the temperature of the exhaust valves rises from 560 to 750°C in the first cylinder, from 673 to 780° in the second, from 676 to 801° in the third, and to 760°C in the fourth cylinder.

The higher temperatures of the valves in the middle cylinders is a consequence of the uneven distribution of fuel mixture among the cylinders, and the comparatively low temperature of the valve in the first cylinder is due to more intensive cooling. In operation under conditions of knocking, the valve temperatures sharply increase.

The temperature characteristics of the GAZ-13 engine were taken under the same conditions as were those of the GAZ-21D. The tests showed that in engine operation under full load with a normal clearance between the valve and the rocker arm, the temperature of the center of the head of the exhaust valve increases on the average from 635° to 780°C when rpm is increased from 2000 to 4000. If the valves do not seal the valve head temperature reaches 870°C. From observations of engines tested in lengthy test stand and road tests it was established that burn-through of the valves precedes a decrease in the gap between valve and rocker arm.

In a GAZ-51 engine temperature was measured in the exhaust valves of the first, third, and sixth cylinders at 1800, 2500, 2800, 3200, and 3500 rpm at full load and with the rpm-governor open. It was found that the valve temperature rises on the average from 650° to 800°C as rpm is increased from the lowest of these values to the highest. Thus, the exhaust valves of the 6-cylinder engine GAZ-51 are subjected to the highest temperatures of all, which is explained by inferior cooling and by blocking of the water jacket in the casting of the cylinder blocks. A number of measures have been introduced to increase the heat-resistance of the valves in GAZ and ZMZ engines. The valve guide bushings on 24 models of flathead GAZ-20, GAZ-51, and GAZ-12 engines were subjected to temperature variation. The measurements were made at the upper part of the bushings where they emerge from the body of the cylinder block. Chromel-Copel and platinum-(platinum-rhodium) thermocouples were used. The tests were conducted at 1000 and 2000 rpm at idle, and 2000 rpm under full load. Under the high load and high speed engine operating conditions a sharp increase in the temperature of the upper zone of the guide bushings was noted; likewise for the temperature of the gases in the exhaust manifold. The maximum temperature recorded at 100% loading was around 500°C for the GAZ-20 engine, a little over 450°C for the GAZ-12, and around 415°C for the GAZ-51. The temperature differences in the guide bushings among the cylinders were affected by the nonuniformity of cooling, differences in the fitted clearances between the bushings and the valves, nonuniformity of the distribution of the fuel mixture among the cylinders, and other factors.

Deformation of Certain Parts of Automotive Engines

A number of design and technological requirements to guarantee durability, wear resistance, maintainability, and repairability are applied to parts of automotive engines. In addition, under conditions of continuous mass production in the manufacture of engine parts, minimum weight of the part, superior processing and machining properties, and minimally expensive methods are specified. At the same time, sufficient attention has not always been paid -- until the present -- in the designing and manufacture of engines to the possible development of deformations in the parts; such deformations to a large determine the subsequent life time of models of a given design.

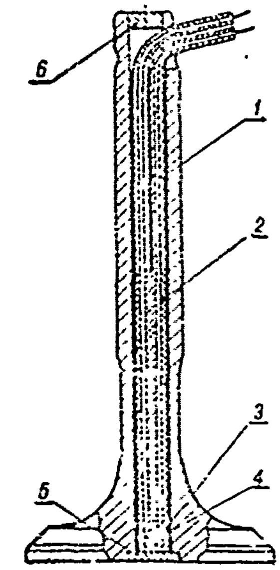


Fig. 17. Diagram of Installation of Thermocouple in Exhaust Valve: 1--vinyl chloride sheath; 2--ceramic double-channel tube; 3--metal cup; 4--hot junction of thermocouple; 5,6--plugs

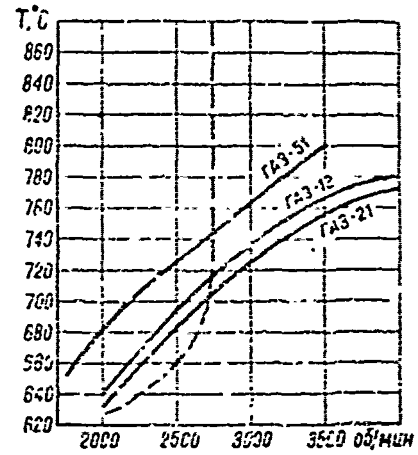


Fig. 18. Temperature of Exhaust Valves of GAZ-51, GAZ-21, and GAZ-12 Engines as Functions of RPM, at Full Load:
---- GAZ-21 engine operated with knocking.

This situation is particularly the case with such complicated parts as cylinder blocks. Conditions resulting from deformation of cylinder blocks include non-perpendicularity of cylinder axes (within the longitudinal plane of the block) away from the nominal position, disturbance of the spacing and parallelness of the axes of the crankshaft, deviations from coaxial alignment and from circular shape of the openings in the main crankshaft bearing pillow blocks, non-planarity of the upper and lower surfaces of the engine block, non-perpendicularity of the front and rear faces of the engine block to the axis of the crankshaft, macroscopic deformation of the cylinders with respect to their axes as well as in the radial direction, etc. These and other deviations appear usually not following machining, but substantially later: either during engine operation or after long storage of the engine block.

In many cases deviations of this type have a greater effect on shortening the service life of the engine before major overhaul than corrosive or abrasive wear arising under service conditions. For example, a high initial ovality of the cylinders causes the gases to pass through into the crankcase of the engine, in turn disturbing the heat balance, increasing the temperature of the piston and piston ring, and breaking the oil film. Substantial blow-by of gases is accompanied by progressive wear, galling of the metal, and sometimes scoring, seizing, and catching of the parts, or complete breakdown of the engine. Ovality of the cylinders or cylinder sleeves is in all cases a consequence of deformation, whether this arises in the separated state, in engine assembly, as a result of uneven loading, or from the action of gas pressure and inertial forces.

Under actual engine service conditions ovality of cylinders can also arise from cavitation damage of their outer surfaces or from the deposition of scale

in the gaps of the fitted zones of the sleeve in the block. Not the least harmful factor in engine life is deformation of cylinder blocks, resulting in a lack of coaxial alignment in the openings of the main pillow blocks of the crankshaft. This non-coaxial alignment results from the deformation of the cylinder block in the vertical longitudinal plane. In measurements formerly made on over 50 new cylinder blocks of GAZ-51 engines at the Gorki Motor Vehicle Plant following lengthy storage, it was established that the maximum nonalignment is 0.008 mm for the second and 0.058 mm for the third opening, with a tolerance [sic] of ±0.02 mm. In GAZ-51 engines taken out for major overhaul, the maximum value of coaxial nonalignment of the main pillow blocks sometimes reaches 0.15 mm and higher.

As a result of this type of deformation the deflection of the axis of the openings of the main bearings is directed upward, as are the upper and lower faces of the cylinder block. Consequences of the coaxial nonalignment of the openings of the main pillow blocks are premature breakdown of the crankshaft and substantial shortening of its service life after regrinding the bearings and replacing the bearing inserts. It should be noted that one of the main reasons for the short life of engines which have undergone major overhaul in comparison with new engines is the absence in most vehicle overhaul enterprises of test procedures for the coaxial nonalignment of the openings in the main pillow blocks in the cylinder block after the [re-]boring operation. When the openings of the main pillow blocks are bored their coaxial alignment is restored, but since deformed end surfaces of the block serve as the basis for this operation, as does the lower face of the block in the boring of cylinders, the perpendicularity of the cylinder axes to the axis of the crankshaft suffers.

The deformation of cylinder blocks, as well as -- incidentally -- other engine parts, occurs as a result of internal and external stresses. A so-called internal stress is one which is present in the part when no external forces are acting. If such a force remains in the part after removal of external influences, for example, heating or cooling, it is called residual. Such stresses can arise as a result of internal transformations which vary over the volume of the part, or of nonuniform plastic deformation, which leads to nonuniform residual linear or bulk changes. Residual stresses are of three types: equilibrated within macrovolumes of the part and having an oriented direction; equilibrated within the limits of small volumes, and disoriented in direction; and equilibrated within the limits of the crystal lattice. For cast iron parts the main type of residual stress is the first type. This gives rise to shrinking of the metal, which is further dependent on thermal and mechanical factors.

So-called external stresses are those which arise in parts under the influence of external loads, either mechanical or thermal.

Mechanical loads appear in machining, assembly, and operation under service conditions. Temperature loading also occurs in service; the most dangerous type involves differences in temperature drop under unsteady conditions of operation, mainly under conditions of cold starts of the engine.

Deformation of parts can be measured by micrometry, the method of artificial datum points -- or incised holes -- or by evaluating the magnitude of the residual forces which arise. In the latter case physical and mechanical methods are

used which are based on the formation of cracks in the surfaces of the part as a result of etching it with a special reagent. The X-ray method is very widespread. The method of magnetic anisotropy finds application. The tensometric [sic] method, which allows both static and dynamic observations of parts of arbitrary shape, has found increasingly wider application in recent years for the measurement of residual stresses and deformation. With the aid of tensometry a few researchers have found the relation between deformation of the cylinder sleeve and gas pressure and rpm, and the effect of these parameters upon stresses in the cheeks of crankshaft, made a more precise determination of stresses in the connecting rods, and studied the effect of deformation of the main pillow blocks on deformations of the shape of the main bearings.

In this section the experience of the Gorki Motor Vehicle Plant in studying the deformation of cylinders, cylinder sleeves, and connecting rods in automotive engines will be discussed. The investigations were carried out under test stand conditions on the engines, with evaluation of the deformation by the familiar micrometry and tensometry, as well as by the method of incised holes. In some of the tests the deformation was evaluated from the variation in oil burning and gas blow-by expressed by the average of the results of 4-hr test stand tests of the engines.

In tests of GAZ-69, GAZ-51, and GAZ-12 engines and their modifications it was established that blocks of 6-cylinder engines were more subject to deformation because their casting configuration is more complex and they are less rigid than the blocks of 4-cylinder engines. The deformation arises primarily from redistribution of the residual internal stresses in the castings during the process of mechanical machining, as well as under the influence of mechanical and thermal loads during assembly and operation of the engine. These deformations bring about a substantial ovalization of the upper zone of the cylinders, with the maximum ovality being in the direction of the wrist pin. This sort of oval configuration is connected with the design properties and the distribution of metal in blocks in flathead engines.

In Table 8 values are given of the maximum ovality of the upper part of the cylinders of 6-cylinder and 4-cylinder engines which have undergone micrometry after completion of various mechanical operations and engine block assembly, and in the process of heating the blocks to 80°C. The measurements pertain to the geometry of the cylinders after they have been honed.

The deformation values in the Table add in some cases and in others mutually cancel; overall, cylinders in a normal environment acquire an ovality of up to 0.05 mm for 6-cylinder engines, and up to 0.03 mm for 4-cylinder engine blocks. Thus, the 0.025 mm maximum ovality specified in the design drawings is often exceeded, causing increased oil burning and gas blow-by. The increase in these indices leads to severe disturbance of the thermal operating conditions of the engine, to drying of the oil film, the appearance of scoring, and intensification of the wear of cylinders and piston rings.

In many cases an initial cylinder ovality of over 0.025 mm shortens the service life of the engine by more than 1.5 - 2 times, since the process of ovalization tends to progress. To a large degree this is the result of uneven

cooling of the cylinders under service conditions, which in turn is caused by varying wall thickness and the presence of casting skin in the passages of the water jacket. A certain, however small, lowering of the deformation of cylinders has been achieved in recent years at the Gorki Motor Vehicle Plant by improvement of the technology of producing castings. Substantial improvement can be obtained through natural aging of the stock for the engine blocks, or, even better, furnace annealing at 600 - 625°C. The latter promotes a partial relieving of the internal stresses in the metal and an increase in the subsequent stability of the geometric parameters of the cylinders; this was confirmed by studies of 40 6-cylinder blocks, in which it was established that natural aging of the stock decreases ovalization of the cylinders by 30 - 35%. Experience in manufacturing 6-cylinder blocks at the Gorki Motor Vehicle Plant also showed that the final finishing of the cylinders should be the final operation. This substantially decreases the probability of subsequent distortion of the geometrical parameters of the cylinders.

Table 8.

Name of operation after which measurements were taken	Ovality of cylinders, mm 6-cyl. block	4-cyl. block
Preliminary machining of main bearing pillow blocks	0.04	0.01
Machining of the openings under the oil pump and distributor	0.03	0.01
Final machining of cylinder block	0.02	0.01
Screwing-on of the head cover studs	0.02	0.02
Screwing-on of the studs under the intake and exhaust pipes	0.02	0.01
Mounting and tightening of the intake and exhaust pipes	0.02	0.01
Mounting and tightening of the cylinder head	0.02	0.01
Stamping of engine numbers on cylinder block	0.02	0.01
Heating of block from 18° to 80°C	0.04	0.02

In research on engines manufactured at the ZMZ it was found that during their operation ovality of the sleeves arises with the major axis of the oval developing mainly in the swing plane of the connecting rod. It is logical to assume that this character of ovalization of wet sleeves is connected with the action of the forces of the piston causing straining in the cross sectional plane in insufficiently rigid sleeves. Sleeves of GAZ-21 engines were subject to the most deformation. Studies and lengthy tests according to GOST 491 -55 of 10 samples of this model engine established that ovalization of cylinder sleeves is to a significant degree the result of initial ovality prior to engine operation.

Sleeve deformation is also observed in GAZ-13 engines. It is analogous in character but its absolute value is much less -- 40-50% less. This was confirmed in 400-hr test stand tests of engines of this model. The lesser ovalization of sleeves of GAZ-13 engines is explained by the fact that they are attached with a bottom flange, and also by the fact that the V construction of the cylinder block is more rigid.

Deformation of the cylinder sleeves in GAZ-21 and GAZ-13 engines was also studied by the method of tensometry. In this work, Constantan strain gages on a paper backing were glued to the surface of the sleeve with a bakelite lacquer, and thermal compensation strain gages were glued on in a direction perpendicular to these. A TA-5 tensometer amplifier was used in the studies, and an MPO-2 magnetoelectric oscillograph was used as the recorder. The process of deformation of the sleeves was recorded on film and was deciphered using the formula:

$$E_n = \frac{2E_k \cdot A_i}{S_D \cdot A_k}.$$

where E_n is the value of the measured deformation, in relative units,

E_k is the range of measurements taken, in relative units,

A_i is the amplitude of deflection of the beam in the recorded process, mm,

A_k is the amplitude of the control signal, mm, and

S_D is the sensitivity of the strain gages.

Epoxy resin, mixed with textolite powder in a ratio of 100:80, was used as a waterproof coating. Tests established the effect of a number of factors and parameters on the deformation of cylinder sleeves. In particular, it was determined that the sleeves in a GAZ-21 engine deform in the upper region of the block under the force of tightening of the nuts on the head cover studs, in a direction perpendicular to the axis of the block, to the extent of 0.007 mm on the manifold side and 0.002 mm on the valve side. In the lower region the sleeve undergoes compression to the extent of 0.005 mm and expansion by 0.0015 mm. In the direction of the axis of the engine block, the sleeve expands by 0.002 mm and is compressed 0.0015 mm in the upper region, and these figures are 0.003 mm and 0.002 mm, respectively, in the lower region (Fig. 19). When torques are applied to the engine with an electrical brake at 600, 1000, and 1500 rpm, the sleeve deformation rises proportionally to the rpm. In this case the sleeve expands in the direction perpendicular to the axis of the block and is compressed in the opposite [sic] direction. In a study of the deformation of cylinder sleeves in a GAZ-13 engine the strain gages were fastened with BF-2 adhesive in locations 20 and 90 mm from the upper ring. In each region, 4 diametrically positioned transducers were installed in the swing plane of the connecting rod, and 4 in the other (orthogonal) plane. In the studies the sleeves were subjected to the deforming action of certain technological factors.

Thus, in tests of the effect of tightening the nuts on the head cover studs with the minimum and maximum forces in the range given by the engineering specifications it was established that there is no difference in the deformation of the sleeves. The effect of the degree of tightening on the deformation of a sleeve was also found for the case where the latter protrudes above the plane of the cylinder block. In this case it is recommended that this [deformation] parameter be limited to a tolerance of 0.02 - 0.05 mm. It was also established from tests that the deformation of the sleeve increases when pulsation of the fitted surfaces and of the fitting seat in the engine block increases, and when the clearances for mounting the sleeve in the cylinder block are decreased.

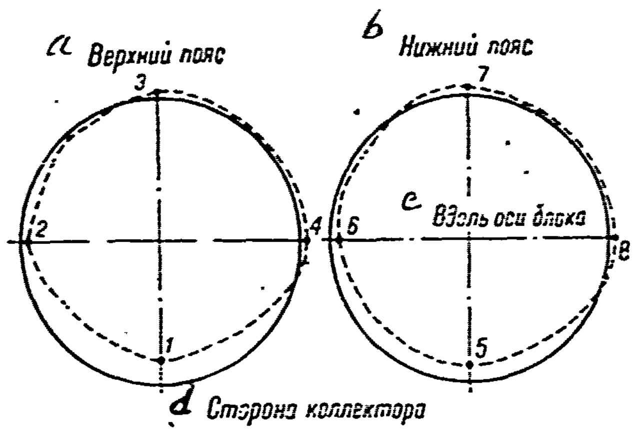


Fig. 19. Deformation of Cylinder Sleeves by Forces of Tightening of Nuts on Head Cover Studs on the Cylinder Block: 1,2,3, etc. = deformation; ---- shape of sleeve after nut tightening.

Key: a = Upper region; b = Lower region; c = Direction of axis of block; d = Manifold side.

With the aim of increasing the stability of the initial geometrical parameters of the cylinders in GAZ-21 and GAZ-13 engines, studies were performed of the conditions of artificial aging of them after the casting of the stock pieces. The following sets of conditions were applied:

1. Aging of the sleeves for 5 hr after casting.
2. Double aging of the sleeves -- for 5 hr after casting and for 5 hr after the first mechanical running-in.
3. Aging of the sleeves for 5 hr after the first mechanica_ running-in.

In Table 9 the average results of tests on 6 GAZ-21 and GAZ-13 engines with sleeves are presented. The above test conditions were used.

Table 9

Conditions No.	Engine model	Ovalization before test, mm	Ovalization after test, mm
1	GAZ-13	0.020	0.085
2	GAZ-13	0.010	0.030
1	GAZ-21	0.035	0.140
2	GAZ-21	0.010	0.110
3	GAZ-21	0.015	0.100

These results were later confirmed in 50- and 100-hr tests of 15 engines. Analysis of the indicates that it is evidently preferable to subject sleeves of GAZ-13 engines to a double artificial "aging" of the stock -- directly after casting, and after completion of the preliminary mechanical running-in. When this method was adopted in the production process, the ovalization of the cylinder sleeves in GAZ-13 engines was reduced by over 2 times. There were no appreciable results in the case of the cylinder sleeves of GAZ-21 engines; aging by the third schedule was used, primarily from considerations of production

expediency.

Initial and subsequent ovalization of sleeves in this model engine was decreased by increasing the fitting clearances. This removed the possibility of deformation of the sleeves during engine assembly and during subsequent operation, associated with uneven thermal expansion of the cylinder block. The connecting rods of the flathead models of GAZ engines were subject to substantial deformation. To gain understanding of this question, more than 80 connecting rods of GAZ-51 and GAZ-21 engines were studied at the Central Engine Laboratory, along with 7 GAZ-51 engines. This research was performed by the author in collaboration with the engineer S. I. Krymov. Some of the studied rods were subjected to natural aging for 50 days. The bending of the connecting rods was measured with a general-purpose instrument; flexure and twisting were determined. The engines were tested for 100 hr under load according to the methods prescribed in the engineering specifications of the plant; the aim was to establish the effect of deformation of the connecting rods on running-in and wear of the parts of the cylinder-piston group and of the crankshaft. Experiments showed that connecting rods of GAZ-51 engines which underwent cold straightening after machining, within a certain time again acquired the same geometric parameters which they had had prior to straightening.

Since connecting rods of GAZ-51 engines are often curved as much as 0.3 to 0.5 mm after machining, straightening them is only a stopgap measure -- such rods should not be sent to engine assembly. In the studies it was also noted that rods of GAZ-21 engines are substantially more rigid; deformation in them is 2 - 2.5 times less than in connecting rods of GAZ-51 engines.

In the tests of rods in engines it was noted that cylinders, pistons, and bearing inserts operating with connecting rods which had flexures of 0.15 mm (that technologically feasible being 0.025 mm) and twisting of up to 0.22 mm (feasible being 0.08 mm) had been run-in suitably after the tests and did not have high wear. When connecting rod flexures were higher than 0.15 mm there were traces of warping on the upper surface of the piston skirts, and when twisting was above 0.25 mm some deterioration of the running-in of the connecting rod bearing inserts was observed.

The above work demonstrated, first, the need in the design of engines to consider the advantage of increasing the rigidity in the design of connecting rods, and, second, the ineffectiveness of the operation of straightening connecting rods, which is used at the GAZ and at many other motor vehicle plants. This applies fully also to pistons; straightening them with the aim of restoring the design values of conicity and ellipticity is also a mistaken operation. Internal straining of the first, second, and third kinds [see earlier this Chap.] and elastic and plastic deformations which are nonuniform with respect to the cross section arise in the cold straightening of parts. Cold straightening reduces the impact strength and causes a breaking of the continuity of the material in locations of concentrated stress.

Character and Dynamics of Wear of Basic Parts

Various models of engines from the Gorki Motor Vehicle Plant and the Zavolzhsk Motor Plant, differing in a number of parameters and in the materials of the friction pairs and the types of fuel used, were studied with the idea of possible later generalizations of the character and the dynamics of wear of the basic parts. The relevant properties of the various models of GAZ and ZMZ engines are covered in sufficient detail in the literature. In the beginning of this section we present the results of 400- and 600-hr test stand tests according to the methods prescribed in GOST 491 -55, in which only the mechanical form of wear due to friction and the abrasive action of wear products is observed. These results were compared with operating wear data after vehicle service mileages roughly corresponding to the length of the test stand tests, and also with intensive wear data from vehicles with long mileage. The latter reflected the influence of the amount of dust in the air, the amount of dirt in the oil, and conditions resulting from "cold" starting and operation at low temperature, which cause corrosion of the friction surfaces.

In Fig. 20 characteristic plots are given of wear with respect to the vertical in cylinders of various models of GAZ and ZMZ engines following 400-hr test stand tests, and also operational wear after 20 - 25×10^3 and 80 - 100×10^3 km of vehicle travel.

In Fig. 21, curves of the dynamics of wear of the cylinders following corresponding periods of testing and service are presented. It should be borne in mind here that the dynamics of the wear of cylinders, plotted from data of micrometry and the method of cut-out holes, is found rather approximately, since the running-in which is necessary after each dismantling of the fitted assemblies has an effect on the subsequent results.

Analysis of the character of the curves of cylinder wear in test stand tests reveals the following characteristics:

1. For all engine models the maximum wear in the longitudinal dimension regularly arises in the upper zone of the cylinders in the region of the end point of the movement of the upper compression piston ring. It can be considered an established fact that the lowered resistance to wear of the upper part of the cylinder is a consequence of the increased gas pressure at the piston rings, aggravated by insufficient lubrication, appreciable local temperature gradients, fuel mixture currents which wipe the surface clean of oil, and also the effect of corrosion from the gases.

2. In all cylinders of flathead GAZ engines the maximum wear around the circumference occurs in the direction of the axis of the crankshaft. The 6-cylinder engines, which have cylinders cast in pairs, are characterized by particularly nonuniform radial wear. This type of ovalization of cylinders in test stand testing can be explained by the specific casting peculiarities of cylinder blocks in GAZ engines -- namely, the fact that in the initial running of the engine, while the cylinder block has not yet been heated up, the maximum ovalization of the cylinders takes place in the direction parallel to the axis of the crankshaft. In this direction the maximum gap between the cylinder and the piston rings is formed, increased gas blow-by occurs, and the oil film dries up. As the block warms up the maximum expansion shifts to the direction per endicular

to the axis of the crankshaft, and a minimum clearance develops in the longitudinal direction, giving rise to increasing wear. In this direction scoring of the cylinder surfaces frequently occurs, resulting in subsequent premature wear. Local supercooling of the cylinders and the flow direction of the fuel mixture — which sweeps away the oil — also have significant effects on the nonuniformity of radial wear.

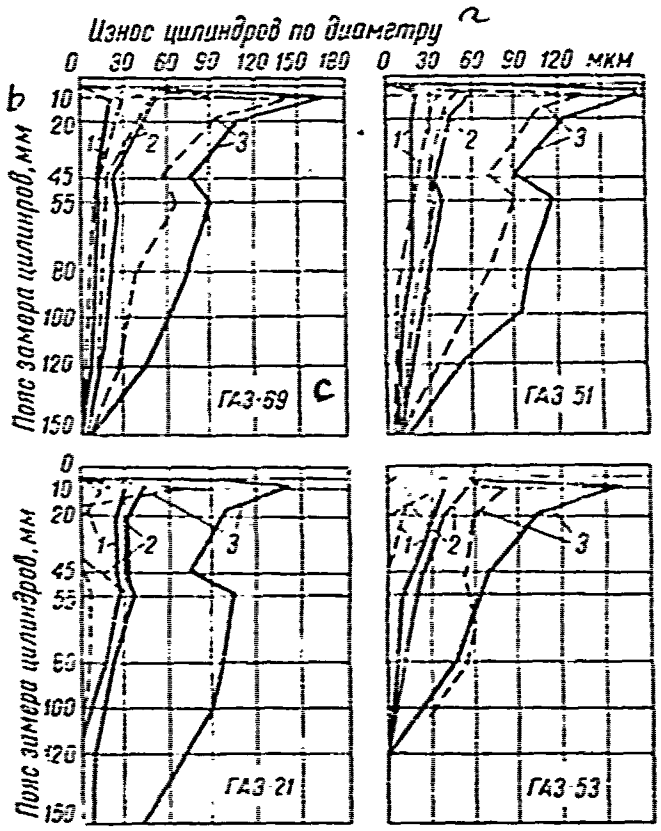


Fig. 20. Characteristic Plots of Cylinder Wear with Respect to the Vertical, Resulting from:

1 — test stand tests of engines according to GOST 491-55;

2 — operation in vehicles with service mileage of 20-25 $\times 10^3$ km;

3 — operation in vehicles with service mileage of 80-100$\times 10^3$ km;

—— in the direction perpendicular to the axis of the crankshaft;

---- in the direction parallel to the axis of the crankshaft.

Key: a = Wear of cylinders, with respect to diameter;
b = Region of measurement of cylinder, mm; c = GAZ-69

3. In overhead valve ZMZ engines having "wet" sleeve inserts, the maximum ovalization occurs in the direction perpendicular to the axis of the crankshaft. The appearance of such ovalization when the wear of the cylinder sleeves is very small is a consequence of deformation of the sleeves, which is particularly observable after 75 - 100 hr of engine operation. The high deformation of wet

cylinder sleeves in these engine models is a consequence not so much of temperature gradients as insufficient rigidity of the sleeves themselves and of the cylinder blocks (Fig. 22). Earlier conceptions to the effect that the nonuniformity of radial wear in the cylinders resulted from the influence of piston deformation, elastic bending of the crankshaft, and bending of the connecting rods were not confirmed in these studies.

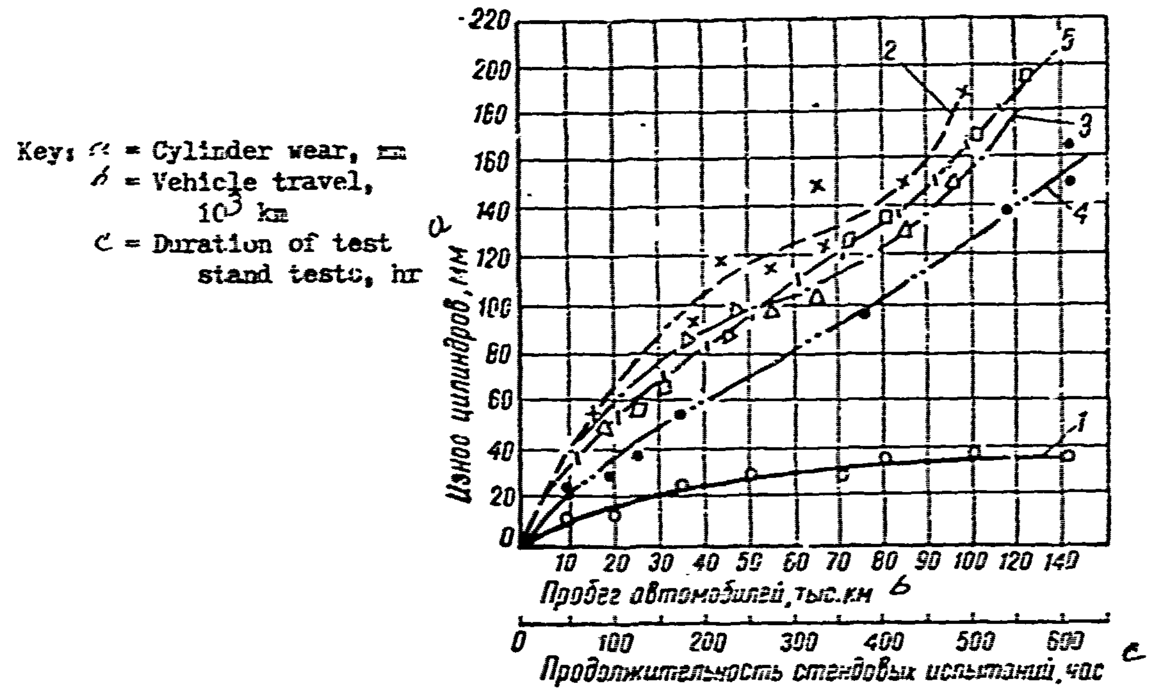


Fig. 21. Dynamics of Medium-High Wear of Cylinders in Engines Produced at GAZ and ZMZ, from the Data of A. A. Kuz'min (GAZ, Design and Experimental Section), Processed by Yu. M. Panov (Gorki Agricultural Institute):
1 — average data from test stand tests of GAZ and ZMZ engine models; 2 — ---- service wear, on GAZ-69 engines; 3 — -·-· same, GAZ-21 engines; 4 — -·- [sic] same, GAZ-13; 5 — -··- [sic] same, GAZ-53.

4. The nonidentity of the character and value of wear of the various cylinders of the engine is a consequence of the differing conditions of the piston rings, nonuniformity of the distribution of the fuel mixture among the cylinders, uneven cooling, and differences in deformation of the cylinders.

5. The plot of the dynamics of cylinder wear from test stand tests characterizes the average fractional increase in wear with respect to time. An exception is the period of running-in, which is filled in very roughly on the diagram, since it is not possible to take measurements over such short time periods.

The diagrams given for operational wear of cylinders of vehicles with mileages on the order of 20 - 25 $\times10^3$ km refer to operating conditions in an average range, with roadways of various qualities and in the absence of factors which

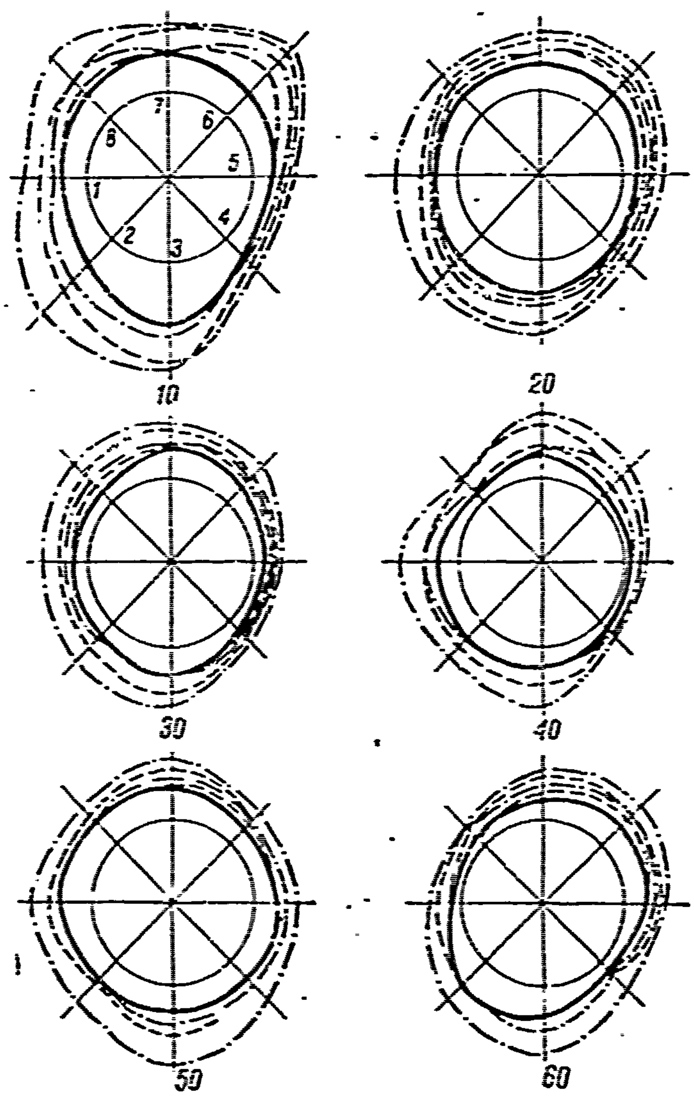


Fig. 22. Wear and Deformation of the Cylinder Sleeve of the First Cylinder of the GAZ-21 Engine, Determined in Various Zones [along the Cylinder Height] with a UPOI-6 Instrument:
—— after 24-hr normal-operation testing; ---- after 50-hr normal-operation testing; -·- after 100-hr normal-operation testing; ···· after 180-hr normal-operation testing; —·— after 400-hr normal-operation testing.

strongly affect the development of high abrasion or corrosion wear.

Beyond this, the frequent factors consisting of the certain amount of dust in the air entering the cylinders and the unsteady speed, loading, and thermal operating conditions of the engine -- and the occasional factor of the "cold" starts -- substantially altered the character of and increased the magnitude of wear in comparison with representative values of wear obtained in engine operation on the test stand.

These differences reduced chiefly to the following:

1. In the running of engines under conditions of vehicle service the wear along the vertical of the cylinders has a sharper peaked [sic] character in the upper zone of the cylinders, due to the much more pronounced action of gas and electrochemical corrosion under service conditions.

There is more wear in the middle and lower regions of the cylinders than under the test stand test conditions, due to the influence of dust in the incoming air and dirt in the oil.

2. In 6-cylinder GAZ conditions under service conditions, in contrast to the situation in the test stand tests, because of the sharper rate of increase of the clearance gaps, the maximum wear in the cylinders occurs in the direction perpendicular to the axis of the crankshaft -- in the zone of the maximum action of the normal component of the pressure [sic] force of the gases. Under service conditions in all types of engines the action of a current of condensed fuel mixture is particularly noticeable, sweeping away the oil and thus creating conditions of boundary friction or even dry friction between the cylinders and piston rings.

3. In some cases, the variation in wear among the various cylinders of the engine, as a function of the respective degrees of cooling, was found to be greater under service conditions than under the conditions of the test stand tests. In particular, in 6-cylinder GAZ engines the wear of the first and sixth cylinders was somewhat greater than that of the others. This results from the less favorable thermal conditions of operation of these cyliniers compared with the others.

4. The plot of the dynamics of the operational wear of cylinders after a vehicle service mileage of around 20,000 km reveals somewhat higher wear intensity compared with engines on the test stand, which is explained by the action of unsteady operating conditions, and by specific operating conditions which cause increased abrasion and corrosion wear of the cylinders.

The diagrams of operational wear of the cylinders along the vertical and around the circumference, in various models of GAZ and ZMZ engines after long vehicle mileage differ even more in comparison with those for test stand tests. From analysis of the former diagrams, confirmed by numerous research reports of different authors, it is possible to conclude that:

1. The wear in the direction perpendicular to the axis of the crankshaft is substantially higher than that parallel to it.

2. The magnitude of wear differs sharply, while its character coincides, in the different cylinders of the same engine. This results from various factors prevailing under the conditions of long service, which contributes to the development of corrosion and abrasion wear.

3. On the dynamic wear curves for the cylinders the periods of complete running-in, operational wear, and terminal wear of cylinders are sharply delineated; the latter period is characterized by a sharp increase in the rate of wear and

tear.

There are also a large number of studies dealing with the wear of piston rings. Thus, S. Ye. Watson and other scientists, using radioactive isotopes, established the relation between ring wear and the dimensions and properties of abrasive particles and the means of generation of the latter in the combustion chamber. They also expressed the hypothesis that the lubrication of the rings has a hydrodynamic character, in contradiction to the assertion that the rings operate under conditions of boundary friction. It is logical to assume that hydrodynamic lubrication occurs only during the interval when the motion of the ring is relatively fast, and that boundary lubrication takes place at the end of each stroke. In some cases, when the fit of the rings to the cylinder surface is not close, blow-by of the gases from the combustion chamber occurs, which blows away the oil film, and dry friction develops.

In this case, chipping of the working surfaces of the piston rings often occurs. One investigator has explained this as the result of gaseous corrosion, and another as the result of carburization of the piston rings and the formation of friable so-called "white" layers. Extreme oil flooding of the piston rings can also lead to unfavorable results, since the temperature of the upper rings may reach 280°C and higher, making possible the thermal decomposition of the oil into solid carboniferous particles, and coking and sticking of the rings.

In normal operation of the piston rings they wear relatively evenly on all surfaces, with a certain increase in the vicinity of the scarf joints. This wear results from friction forces, as well as from the action of abrasive particles which come from the wear products and the air; it increases when lubrication is insufficient. The higher wear of the rings in the region of the scarf joints in comparision with the rest of the outer circumferential ring surface is connected with the nonuniformity of ring pressure on the cylinder walls, for a given pressure design diagram. The rings wear not only along their vertical surfaces, but also in the height dimension, with the bottom surface wearing several times faster than the top.

The wear of the piston rings in the test stand tests of all engine models proceeded in agreement with the normal wear dynamics for porous-chromed upper piston rings:

1. The upper compression rings had superior wear resistance in comparison to the other rings, due to the chrome coating of their outer cylindrical surfaces.
2. When the wear of the upper compression rings was lower, that of the other rings was also.
3. The maximum wear with respect to the radial thickness occurs on the rings which operate in the most worn cylinder.
4. The maximum wear of the piston rings with respect to the radial thickness occurs in the vicinity of the scarf joints; this is specified in the initial pressure design diagrams for the rings of GAZ and ZMZ engines.
5. The extremely insignificant wear of the rings with respect to the height dimension -- less than 0.015 mm -- is a result of the absence of the effect of dust in the air and oil, since this form of wear is usually what furnishes the abrasive character.

The wear of piston rings in service, with respect to radial thickness and the height dimension, over an engine operating period in service of around 20,000 km differs little in the character of its distribution from the wear in test stand tests, however it is substantially greater in absolute value, because of the influence of abrasion and corrosion factors. When rings are operated for very long service periods the character of their wear becomes even more sharply expressed, particularly in the region of the scarf joints.

The dynamics of radial wear of rings is analogous to the wear dynamics of cylinders; it is represented by a classical curve which delineates initial, operational, and terminal wear (Fig. 23). The curve of the dynamics of wear of the rings in the height dimension under conditions of long service is a broken curve with a constant tendency to increase, representing decrease or increase of the rate of wear in the different stages, depending upon the conditions of dust in the air and dirt in the oil.

The gradual wear of the rings in the radial direction and the height direction leads to a proportional drop in ring elasticity and to an increase in the gap in the scarf joints -- and, consequently, to increased gas blow-by, a drop in the compression in the cylinder, increased fuel consumption, decreased power, and other consequences associated with the necessity to change the rings.

One of the most frequent causes of premature malfunctioning of piston rings is sticking of the rings in the piston grooves. A number of investigations have been devoted to this phenomenon; the conclusion is basically that sticking of the rings results from oxidation and condensation of the fuel and oil, lowering of the rigidity of the piston lands at high temperatures, deficient sealing of the cylinder-piston ring fitted assembly, and insufficient distance from the working face of the piston to the upper piston groove.

Switching to a 3-groove piston in flathead GAZ engines and increasing the distance of the upper ring from the working face of the piston sharply lowered the number of cases of ring sticking. The pistons of automotive engines have different friction surfaces working under different conditions. The friction on the working surface of the piston skirt has a predominantly fluid character, and the wear resistance of this surface is not a limiting factor in the service life of the piston, with the exception of those rare cases involving the development of scoring, due to severe deformation or overheating.

The degree to which deformation occurs is governed by the nonuniformity of the temperature field of the piston as it operates, manifested in a sharp temperature drop between head and skirt. A particularly uneven temperature distribution is observed in pistons of flathead models of GAZ engines, which have a U-shaped slot in the skirt. The friction surface fitted to the piston pin also does not determine the service life of the piston, despite conditions of boundary lubrication and perceptible [sic] sign-varying dynamic loads. Usually the upper piston grooves under the piston rings were subject to the greatest wear. The conditions of wear and tear of piston grooves are determined mainly by the degree and character of deformation and wear of the cylinders and piston rings, the magnitude of the initial clearance between the groove and the ring in the piston, and vibration of the rings during engine operation, but, most fundamentally, by the amount of abrasive particles entering the fitted assembly.

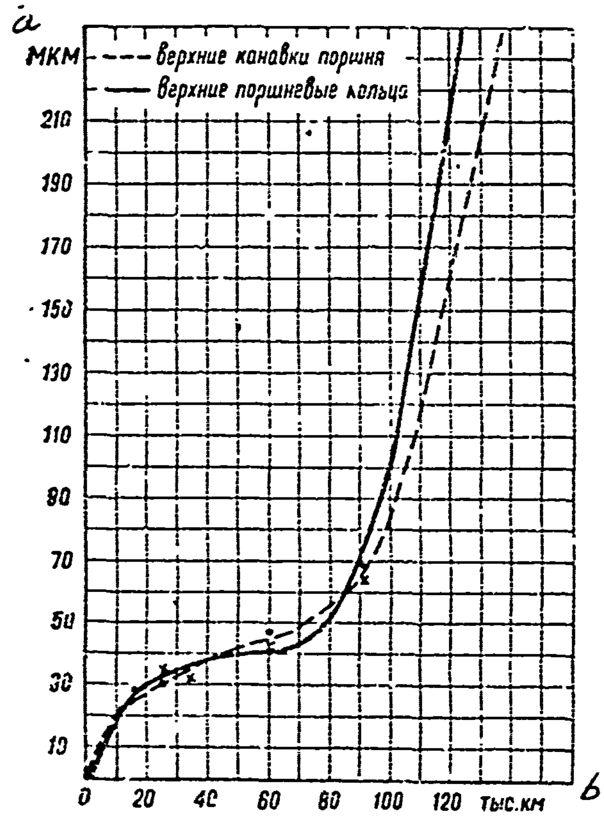


Fig. 23. Dynamics of Wear of Upper Piston Rings and Grooves of the GAZ-53 Engine in Vehicle Service, from Data of A. A. Kuz'min, Processed by Yu. M. Panov:
—— upper piston rings; ---- upper piston grooves.

Key: a = micron; б = thousand km

The insignificant amount of wear of the grooves with respect to the height dimension in 400-hr tests of engines on test stands and the relatively higher amount of wear of these surfaces during the operation of engines under service conditions in motor vehicles can be explained by the absence of the influence of abrasive dust in the former case.

In the tests it was noted that the wear in the lower piston grooves was substantially less intense than in the upper grooves; this is explained by the fact that the lower piston rings operate under conditions of less stress. Thus, the service life of the piston is limited by the wear on the upper piston ring, with the lower face of the groove wearing faster than the upper. The above establishes the need to develop measures of increasing the resistance to abrasive wear and tear of the end surfaces of the upper piston grooves.

Wear in the swinging linkage between piston and connecting rod, involving the friction surfaces of the wrist pin, openings in piston bosses, and connecting rod bushing, does not limit the service life of the engine. The wrist

pin is subjected to the constant dynamic action of sign-varying loads, and its reliability of operation is determined not so much by the amount of mechanical wear and tear as by its resistance to stress fatigue. The character of the wear of the connecting rod journals on the crankshaft has some influence on the character of the wear of the wrist pins and the surfaces to which they are fitted. The upper parts of the openings in the piston bosses, along with the connecting rod bushings, which are acted on by the pressure of the gases, are subject to the greatest wear.

The crankshaft bearings operate under conditions of hydrodynamic lubrication under the continual action of sign-varying loads due to the inertial forces and gas pressure in the cylinders of the engine. A large number of studies of wear in this fitted element have been carried out in the factories and in scientific laboratories.

Under the mutual movement of the friction surfaces of the crankshaft and the bearing insert, an oil wedge develops between them. Its supporting force depends upon the rate of relative movement of these surfaces and upon the viscosity of the oil. Beyond this, the wear conditions of the bearings are determined by a whole series of design, engineering, and use factors. From an analysis of the character of the wear of the crankshaft connecting rod bearings it was established that in GAZ-51 engines, with unsymmetric connecting rods, the radial wear of the inserts is greater underneath the short shoulder of the connecting rod than underneath the long shoulder. In the middle zone of the insert the wear was a little less than under the short shoulder. The upper inserts in the connecting rod bearings were subject to greater wear than the lower ones.

The bearings of type GAZ-69 engines, and those in all the models of overhead valve ZMZ engines wore substantially more evenly as a result of the symmetrical design of the connecting rods in these engine models. The inserts of the main bearings wore more evenly along the axial direction than did the connecting rod bearing inserts. The radial wear of the lower inserts was higher than that of the upper. The inserts of the middle main bearings wore more than the same kind of inserts in bearings at the ends. A characteristic property of wear in overhead valve GAZ-21 engines and in other engines having cast crankshafts is that the wear in the connecting rod bearing inserts is less than that in the main bearings. This is attributable to the presence of hollows in the connecting rod journals, which are effective as dirt traps. Operation of the engine at low rpm is accompanied by the possibility of contact friction in the friction pair consisting of the shaft and the shaft bearing; on the other hand, when rpm is increased, the temperature of the inserts rises, and thus the resistance of the babbit layer to stress fatigue is lowered. The latter leads to premature chipping of the babbit, causing accelerated wear of the crankpins.

In most cases the areas of chipping develop in a zone of contact friction, which confirms their origin — not only in fatigue phenomena but also in high developed temperatures under conditions of friction without lubrication. The service life of crankshafts of flathead GAZ engines is limited, as a rule, by the condition of the connecting rod journals, which are subject to the most intense and uneven wear. The connecting rod journals usually wear 1.5 - 2 times faster than the main journals, with conical wear as well as radial wear being

characteristic for connecting rod journals. The theory of elastic bending of the crankshaft has been widely applied in relation to the appearance of the latter phenomenon. Some authors have attributed this kind of wear to the angle of inclination of the oil passages and the direction of flow of mechanical particles in the oil.

N. F. Strunnikov exhaustively proved that the cause of conical wear of the journals in GAZ-51 engines is the asymmetry of the connecting rods, and the effect of other factors is secondary. In general, cases of relatively intensive wear of crankpins can be explained by three basic factors: severe loads on the connecting rod bearings, the action of abrasive particulate contaminants in the oil, and inferior conditions of oil feed to the connecting rod bearings. The main journals wear more evenly than the connecting rod journals, both along their length and around their circumference. The middle main journals wear 1.5 - 2 times more than the end main journals. The cast crankshafts made from nodular cast iron in the overhead valve type GAZ-21, GAZ-13, and GAZ-53 engines have significantly higher wear resistance than the steel crankshafts of flathead GAZ engines. This property of cast crankshafts is governed mainly by the high rigidity of nodular cast iron and by th actual design of the crankshafts.

Main and connecting rod journals on steel crankshafts were found to need regrinding after a vehicle service life of $50 - 60 \times 10^3$ km, while cast crankshafts did not need regrinding even after a vehicle service mileage of $100 - 110 \times 10^3$ km.

In addition to the above it should be noted that wear of the journals on cast iron crankshafts is characteristically much more even than that of journals on steel crankshafts. The character and the course of the wear of the connecting rod and main journals on the crankshafts indicates that:

1. The absolute values of the maximum wear of crankpins of all models of flathead GAZ engines is much higher than that of the main journals; while the opposite relation holds in overhead valve engines.
2. The crankpins on the crankshafts of GAZ-51 engines exhibit conical wear, while other engine models have comparatively even wear of crankshaft journals; which demonstrates the inadvisability of asymmetric connecting rod designs.

The parts comprising the valve - camshaft mechanism under normal conditions of engine operation do not limit the service life, even in the case of relatively severe friction conditions of certain friction pairs. In contrast to the crankshaft journals, the camshaft journals of all GAZ and ZMZ engine models wear evenly, both around the circumference and along the axis.

The valves, which work under conditions of boundary lubrication, are subjected to dynamic loads as they approach the valve seats in the cylinder block at high speeds. The exhaust valves, in addition, are subjected to the intense heat of the exhaust gases, which, in combination with insufficient lubrication and possible bending of the parts of the valve mechanism, promotes the development of contact friction, seizing, scoring, and catching of the friction surfaces of the guide bushings and the valve stem.

Under normal conditions of running-in of the valve - valve guide bushing friction pairs, the fairly high degree of conical wear of the bushings which develops

with long operation does not make replacement of parts necessary. The most dangerous eventuality in engine operation is burning through of the valve heads.

The friction pair consisting of the push rod and the openings in the engine block has a tendency to wear steadily and evenly with long engine operation; mechanical wear here is not determinative of the overall service life of the engine.

This statement applies equally to the friction surfaces of the tappet head and the cams on the camshaft, provided there is no scoring and no prematurely high wear in this fitted assembly. In the latter case the molecular mechanical form of wear develops. It should be noted that the incorporation of hot phosphated cast iron surfacing on the working surface of the tappet head in the production of all the engine models has practically eliminated scoring of this surface.

Chapter IV

Ways of Increasing Automotive Engine Life

Design Methods of Increasing Engine Life

Progress in world automotive technology is accompanied not only by the creation of new and promising engines but also by the continuous development and improvement of models already in production. The competitive position of the different motor vehicle firms in many ways depends upon the engines in their vehicles -- on their rated power, economic efficiency, simplicity of operation, adaptability to repair, freedom from breakdown, and life time.

In Soviet automotive engine manufacture the reliability of the engine has always been the primary question, and the increase in the life time of each new engine model over the old model has been, first of all, the result of painstaking labor of the designers in the motor vehicle plants. This applies fully as well to the engines from the Gorki Motor Vehicle Plant, the life time of which has gradually increased, beginning with the GAZ-A and GAZ-M1 models and ending with the current models being produced at the Zavolzhsk Motor Plant.

The design methods of increasing engine life are quite varied. They are based primarily on modernization of the engine models produced by the factories and they amount to the choice of the latest solutions with regard to the configuration of the cylinders and the parts of the valve-camshaft mechanism, the establishment of the optimum ratio of stroke to cylinder diameter, and improvement of the structural elements from the point of view of filtration of oil and air as well as of maintaining optimum thermal conditions of engine operation. The choice of appropriate wear- and heat-resistant materials for the main parts, application of electrochemical or chemical methods of treating friction surfaces, and designation of optimal clearances in the fitted parts assemblies are among the more important design topics. Many such approaches are well known, but some are insufficiently grounded and call for thorough analysis. Thus, a large number of research reports have been devoted to the choice of the optimal ratio of stroke to cylinder diameter S/D for various engine types. In these

studies the effect of the ratio of these parameters on the efficiency and economy of the engines, upon engine bulk, and upon heat transfer to the walls of the combustion chamber and to the piston head is treated; however, the question of how these relate to engine life has been neglected. Meanwhile, experience has shown that for a single engine model a decrease in the S/D ratio due to an increase in cylinder diameter lowers cylinder and piston ring wear to a certain degree. which is completely in accord with the theoretical assumptions of B. Ya. Gintsburg. In current foreign engine production the S/D ratio varies within the limits of 0.6 -- in the Ford Anglia -- to 1.06 -- in the Nissan Datsun.

In the development of engine production at the Gorki Motor Vehicle Plant and the Zavolzhsk Motor Plant a gradual lowering of the S/D ratio is also seen. Thus, for GAZ-51 engines, it is 1.34; for GAZ-69 engines, 1.22; for UAZ-450, 1.15; for GAZ-21 and GAZ-13, 1.00 and 0.88, respectively, etc. To an approximation, the optimum S/D ratio may be regarded as close to 1. As the ratio increases, the average piston speed increases, which lowers the life of the piston rings; and when the ratio is decreased, the friction path of the ring on the cylinder is decreased and the cylinder surface is subjected to higher specific loads. Among the less-studied design parameters which affect cylinder and piston ring wear is operating nonuniformity of the cylinders, which is particularly seen in multicylinder in-line engines, specifically the GAZ-51. Influences on uneven operation of the cylinders which cause uneven cylinder wear, in addition to nonuniformity of the temperature field, include uneven mixture distribution, variations in the composition of the mixture going to the different cylinders, and the variations in the compression ratio as high as 0.2 and in the spark advance angle as high as 2° which occur among the different cylinders.

Thus, under conditions of service of GAZ-51 engines, some of the cylinders suffer high wear as a result of extremely rich mixtures, extreme spark advance, and operating conditions which approach knocking. The new models of GAZ and ZMZ engines have a substantially lower disparity in the operating conditions of the cylinders.

A very important design parameter which affects engine wear is the intensity of crankcase ventilation. Joint research carried out at the Central Engine laboratory of the GAZ and at the Laboratory of Isotopic Methods of the NAMI showed that with a closed crankcase ventilation system an increase of oil burning by 15 - 25% is observed, along with some increase in the wear of the parts of the cylinder-piston group (Fig. 24). This is attributable to defects in the design of the ventilation system and to flow of the inactive [sic] exhaust gases, which contain sulfuric and sulfurous compounds and promote corrosion wear, around the parts of the cylinder-piston group. Moreover, when the ventilation system is open the crankcase oil ages faster, the probability that road dust will enter the engine increases, and the toxicity of the exhaust gases is higher. Thus, despite a number of studies in this area, the problem of systematic design of the crankcase ventilation system has not yet been solved. However, one would suppose that the ventilation system must be closed, in order to lower the toxicity.

From among the large number of design factors affecting the character and rate of wear, the choice of the materials of the main parts of the engine is

particularly important.

Research results in the area of increasing the wear resistance of cylinders are expecially interesting. As is well known, inserts of anticorrosive high-alloy "Nirezist" type cast iron with a nickel content of 16 - 17.5 % have been used in all models of GAZ and ZMZ engines, and in recent years also in ZIL engines, to lower wear in cylinders and cylinder sleeves. The inserts are pressed into the upper part of the cylinders of GAZ engines and the cylinder sleeves of ZMZ engines to a depth of 50 mm. These inserts, introduced into the design of the engines by A. A. Lipgart and N. F. Strunnikov, are used mainly with the intent of lowering corrosion wear in the upper part of the cylinders. Many years of experience in their use has shown that the material of the inserts not only resists corrosion but also resists abrasion outstandingly well. More than once, attempts to replace this material with something less expensive were unsuccessful. Thus, experiments were carried out at the Gorki Motor Vehicle Plant on the use of wet sleeves made of standard grey cast iron of the perlite class, type SCh-24-44, without an anticorrosive sleeve, and the same with sleeves specially cast of high quality alloy iron, corresponding to type SCh-35-36 in its mechanical properties. The engines used were GAZ-21.

From tests of the engines in vehicles it was found that the maximum wear of the sleeves made of the experimental iron was higher than that of standard sleeves without inserts (by 1.77 times) and an that of sleeves with inserts (by 2.5 times). The wear of piston rings and pistons working in pairs with cylinder sleeves having inserts made of Nirezist had the least wear of all. Studies directed at lowering the cost of inserts made of Nirezist by lowering the nickel content in it to 12.0 - 15.0% gave, as a rule, negative results, due to the high tendency of such inserts to deform. In this case, uneven joining of the Nirezist insert and the basic metal was a rather frequent occurrence. In specially designed studies it was determined that lowering the nickel content in the Nirezist inserts leads to a partial decomposition of the austenite to martensite, at high temperatures, and to a substantial increase in hardness due to the formation of a large amount of carbides. It should be noted that the inserts, in addition to their high cost, substantially complicate the technology and the process of manufacturing the cylinders.

With the aim of replacing the Nirezist and producing a cylinder without inserts, a chromium-silicon alloy with a content of 13 - 16% Cr was developed at the NAMI, in conjunction with a thiocyanate coating to be applied subsequently, to improve running-in. The hardness of the stock piece after annealing -- which latter is done to improve the machinability of the casting -- is HRC 28 - 32. The problem of using chromium-silicon cylinder sleeves has not been solved yet: at issue are the difficulty of machining and the frequent cases of scoring of the cylinder surfaces during running-in.

Beside the search for the most wear-resistant and most easily machinable materials for cylinder sleeves a great deal of attention has been given to the possibility of using metallic coatings which satisfy these requirements. In particular, chroming the working surface is one of the effective means of increasing the service life of cylinders. Thus, according to literature data, the wear under service conditions of chromed cylinders is 4 - 7 times less than that

of unchromed cylinders, for ZIL-120 engines, and the piston ring wear is 1.5-2 times less. Similar data characterizing the effectiveness of chromium coatings of cylinders have been offered for a number of other automotive, tractor, aviation, and marine engines. Experiments carried out at the GAZ confirmed the positive effects of chroming cylinder sleeves.

Highway tests of three GAZ-21 engines with chromed and standard cylinder sleeves established that the average wear of chromed sleeves after a vehicle travel of 50×10^3 km, in a "Volga" automobile is less by a factor of 2; however, the radial wear of the piston rings was somewhat higher.

For engines with dry cylinders chroming is a complex and expensive process. In this case, using a hard chrome coating instead of the present porous chroming of compression rings shows promise, for increasing the wear resistance of the cylinders. Many studies have shown that porous chroming of piston rings, along with its positive qualities associated with relatively fast running-in and good wettability by oil, has a number of important negative features. The most serious is the chipping and spalling of the edges of the flat surfaces, and, consequently, the development of scratches on the cylinder surface; also the high coefficient of friction of porous chrome in comparison with smooth, the possibility that acids capable of causing corrosion may penetrate beneath the porous chrome layer, and the uncontrollability of the process of de-chroming.

The process of hard chroming of rings with knurled cylindrical surfaces does not have these deficiencies. Accordingly, test stand tests of 20 UAZ-450 and GAZ-51 engines with the upper compression piston rings covered with porous chrome or with rings with knurled surfaces covered with solid chrome were set up under laboratory conditions. The correlations of the test results, which are presented in this book, showed that the experimental rings have 1.5 - 2 times less wear with respect to the radial thickness than the standard rings, at relatively the same values of cylinder wear. In recent years close attention has been paid to piston rings and in particular to piston ring materials.

A large number of studies conducted in this area are described in detail in the literature. Experiments on piston rings made of titanium and tungsten alloys were also carried out at the Gorki Motor Vehicle Plant. From numerous test stand and road tests of GAZ-51 engines and their modifications important advantages of these rings over standard rings were found: high elasticity and wear resistance. On the other hand, titanium alloy and tungsten alloy piston rings have not as yet been used on 6-cylinder GAZ engines, because of the tendency which these engines have toward increased frequency of scoring of the cylinders. In addition, a certain increase in the wear of the end surfaces of the piston grooves was noted. Groove wear limits the service life of the pistons.

Various foreign firms have solved this problem either by using special wear-resistant inserts or by applying the method of anodic oxidation of the pistons. Future use of inserts of this type is also planned for ZMZ engines. Chroming of the end surfaces of the upper compression piston rings was tried under laboratory conditions at the GAZ with the aim of lowering the wear of the piston grooves. The favorable results of these experiments were confirmed in service tests of 3 GAZ-21 engines after a vehicle service mileage of

50×10^3 km. However, despite the theoretical effectiveness of this method, its realization in practice is prevented by the technological complexity of chroming the end faces of the rings under conditions of large-scale serial production.

Many studies and published articles have been devoted to design methods of increasing the life of piston rings. Actually, any parameter of the piston ring -- whether elasticity, height, width, cross-sectional shape, pressure distribution, or scarf joint design -- affects the life of the parts to which it is fitted and of the engine as a whole, as of the ring itself. For example, reducing the width of the inside conical faces of the compression rings of flathead 4-cylinder GAZ engines increases oil burning from 56 to 110 g/hr, as specially designed tests under laboratory conditions showed (Fig. 24). The introduction of piston rings with "scrapers" into production at the GAZ and the ZMZ lowered oil burning in all engine models by an average of 20 - 30% and sharply decreased the number of cases of ring sticking.

The location of the upper piston ring on the head of the piston is very important. Thus, the increase of the sub-ring space on the pistons in GAZ engines which resulted from the change to 3-groove pistons substantially increased the wear resistance of the rings and completely eliminated cases of burning-through of the shoulder [sic] on the head of the piston. Incidentally, the latter was also contributed to by the change on some modifications of the engines from the Cu-Si-Al alloy formerly used for the pistons to heat-resistant Silumin with 11 - 13% silicon.

The crankshaft is one of the fundamental parts whose service life limits the overall life of the engine. The design features of the crankshaft to a large degree determine the character and the amount of wear of the main and connecting rod bearings. Thus, although the GAZ-51 engines have proven themselves to be outstanding over the long period they have been on the scene, until recent years there have been very frequent occurrences of near-melting of the second and fifth crankshaft bearings, under service conditions. Only in 1967, thanks to the research of the Gorki engineer A. A. Kuz'min, did it seem possible to find a design solution to prevent this phenomenon. The research discovered that nonuniform oil pressure arose around the journals of the middle main bearings during engine operation. The maximum pressure was developing on the side of the journal opposite to the exit opening of the oil passages which feed oil to the connecting rod bearings. The oil was fed to the second and fifth connecting rod bearings from the zone of minimum pressure. This caused underfeeding of the oil, near-melting of the bearings, and even scoring of the crankshaft journals. When crankshafts with oil passages which fed oil to the connecting rod journals from the zone of the maximum pressure developed in the gaps of the main bearings were put into production at the GAZ, this deficiency was removed, and thereby the life time of the crankshafts in GAZ-51 engines and their modifications was increased.

Since 1957 at the time of the initial mass production run of the GAZ-21A engine in "Volga" automobiles at the Gorki Motor Vehicle Plant, the manufacture of crankshafts made of type VCh-50-1.5 nodular cast iron with with a coating on top of the casting scale contour has been in effect. The cast iron crankshafts wear from 2 - 3 times less than the crankshafts on GAZ-20 and GAZ-69 engines.

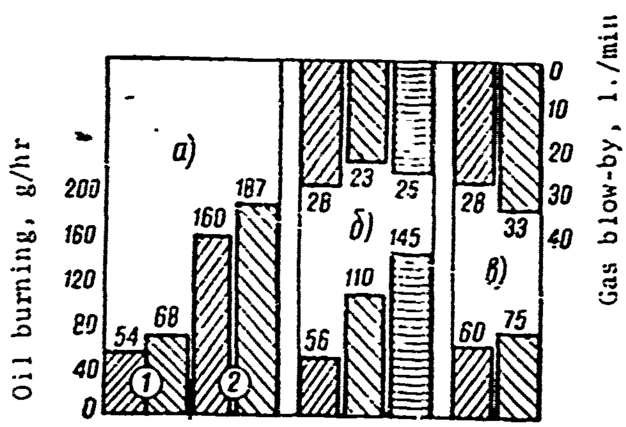


Fig. 24. Effect of Certain Factors on Oil Burning and Gas Blow-By in Flathead GAZ Engines:
a -- crankcase ventilation:
1 -- GAZ-69; 2 -- GAZ-51;
▨ -- without ventilation; ▧ -- with ventilation
b -- width of beveled edge of compression rings:
▨ -- beveled edge 3.08-4.18 mm;
▧ -- beveled edge 0.45-1.00 mm;
▤ -- without beveled edge
c -- elasticity of the piston rings:
▨ -- elasticity within limits of TU [Engineering Specifications];
▧ -- elasticity lowered by 300 - 400 gr [Translator's note: Unknown abbreviation.]

The results of measurements of crankshaft journals of engines in operation in the motor pool at the Gorki Motor Vehicle Plant and in other motor pools showed that wear of the crankpins of cast iron crankshafts is nearly 4 times less, and that of the main journals is 1.8 times less than journals of steel crankshafts. Wear of the crankpins of GAZ-13 engines is 2.3 times less, and that of main journals is 2 times less than on the steel crankshafts of GAZ-12 engines. About the same numerical relation applies between the wear of the journals of the cast iron crankshaft of the GAZ-53 engine and that of the steel crankshaft on the GAZ-51. This appreciable advantage of cast iron crankshafts is explained first of all by the high durability and wear resistance of nodular cast iron, as well as purely design factors -- namely, excessive lining of the crankshaft journals at the expense of crankpin diameter, manufacture of journals with hollows having spaces to catch wear products, and the fact that the GAZ-21 has five pillow blocks.

The bearing inserts are also involved simultaneously with the above design means of increasing engine life. In this respect, connecting rod bearing inserts made from ferroaluminum strips displayed substantially higher fatigue

strength than the formerly used trimetallic inserts and metalloceramic sublayer , and even more so than bimetallic inserts with SOS-6-6 alloy antifriction coatings; and they allowed a higher gap in the friction pair crankshaft-bearing insert.

The contemporary tendency to increase the rated power and the rpm of the crankshaft has a notable effect on the operating conditions of the parts of the valve-camshaft mechanism. To increase their reliability, overhead location of the camshaft is being used increasingly widely abroad. This eliminates deviations from the valve lifting relation furnished by the shape of the cam. The use of an overhead camshaft decreases the number and the weight of the parts of the valve-camshaft mechanism. Thus, on the Pontiac 216 engine, the weight of the parts was reduced by 45% and the inertial force acting axially on the valve was reduced by 27%. The drive mechanism of an overhead camshaft is somewhat more complex than that of a camshaft located in the cylinder block, but this is entirely justified by the increase in the reliability of the total design. Of the engines in the planning stage at the Gorki Motor Vehicle Plant, the use of an overhead camshaft is planned only in the design of the V-6 6-cylinder engine.

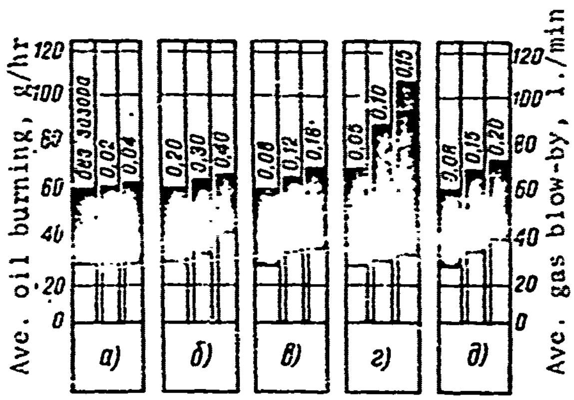
In recent years, in connection with the operation of engines under higher thermal stress and the use of high-ethyl gasolines, exhaust valves have required the highest order of attention. As a result of lengthy exploratory research, the most suitable combinations of materials for valves and for the heat- and corrosion-resistant surface coatings on the faces of valve heads have been found. Thus, for GAZ-51 engines intended for export and for use in the South, for certain modifications of GAZ-69 engines, and for GAZ-21A engines, the valves are made of EP-303 steel; for the D and D1 modifications of the GAZ-21 engine with high compression, valves made of EP-303 steel with WChNi-1 coatings are used; and for all V-8 ZMZ engines, the valves are of EI-992 steel with WChNi-1 coatings and sodium filling.

The change to cast iron camshafts in combination with steel tappets will be accompanied by a substantial increase in the life of the parts of the valve-camshaft mechanism. At present this method is in the stage of design and engineering development. The advantage of such a change is connected with the fact that the existing classical design of the steel camshafts of GAZ and ZMZ engines with tappets having cast iron coatings with subsequent phosphatization -- which has fully proven itself in the GAZ [sic] and GAZ-21 engines -- does not provide the required running-in and wear-resistance properties of the fitted parts in V-8 ZMZ engines.

The theoretically- and experimentally-based choice of initial clearances in fitted parts assemblies is another design means of increasing engine life.

The chief criteria of proper setting of the initial clearances are the furnishing of the best lubrication and maximum heat conduction from the friction surfaces, as well as the minimization of pulsating loads which intensify the development of stress fatigue. In the present research work over 100 samples of engines of various GAZ and ZMZ models were inspected, and some of these underwent testing for long running times in vehicles following their test stand testing. Evaluation of the break-in qualities and wear resistance of fitted parts assemblies with various initial clearance values was carried out visually, by micrometry, and also from indirect indicators -- namely, oil burning and gas

blow-by into the engine crankcase. In the latter case the evaluation was conducted under the previously adopted test conditions for fully broken-in engines (Fig. 25).



Clearances in fitted assemblies, mm

Fig. 25. Evaluation of Optimum Clearances in Fitted Parts Assemblies from the Indices of Oil Burning and Gas Blow-By:
a -- cylinder - piston skirt; b -- cylinder - piston head; c -- piston - piston ring; d -- bushing - inlet valve; e -- bushing - exhaust valve.

It was found that in the fitted assembly cylinder - piston skirt in the direction of the working part of the skirt the initial clearance should be between 0.006 and 0.018 mm, for pistons made of high-silicon Silumin. These limits are optimum with respect to wear resistance and running-in properties of the fitted assembly. The clearance between the upper zone of the piston and the cylinder wall has a substantial effect on the subsequent sticking of the upper piston rings and pitting of the piston in the upper groove behind the ring. A theoretical and experimental study of this problem by B. Ya. Gintsburg showed that it is necessary to minimize the clearance in this fitted assembly in order to reduce the flow of gas in the zone where throttling occurs and to increase the heat transfer from the piston head to the cylinder wall.

Studies carried out at the GAZ confirmed the advantage of setting the minimum possible clearance in this fitted assembly; the range determined was 0.2 - 0.3 mm.

The end gap in the fitted assembly piston ring - piston groove influences the pumping action of the rings, the blowing of gases from the combustion chamber to the engine crankcase, the vibration of the rings during operation, and the resistance of the rings to gumming up. Most of the experiments, as well as more thorough studies, carried out at the Gorki Motor Vehicle Plant confirmed that it is necessary to set the initial clearance sufficiently small to lower

the gas blow-by and, to some extent, the oil burning, but sufficiently large to ensure movability and twistability of the ring in the groove. For GAZ and ZMZ engines the optimum ranges of these clearances are for the upper rings 0.050 - 0.082 mm, and for the other rings 0.035 - 0.067 mm. The gap between the inside surface of the ring and the bottom of the piston groove does not have a substantial effect on oil burning and gas blow-by.

The operation of the fitted assembly piston - wrist pin - connecting rod is associated with applied loads which change in sign under conditions of insufficient lubrication. The clearance in this fitted assembly should ensure fluid friction with a minimal layer thickness. Most investigators consider it expedient to choose a small clearance, since a larger clearance lowers the margin of safety of the fatigue strength of the wrist pin and the piston head. When the clearance in the above fitted assembly is extremely small, however, the oil film may break due to deformation of the wrist pin. Also, extreme tension in the pressing of the wrist pin into the piston causes piston deformation, and sometimes scoring and premature wear of the piston skirt in the direction of the axis of the wrist pin. This forms the basis for the recommendation that these clearances be between 0.0025 mm and (tightness minus 0.0025) mm in the connecting rod - piston group subassembly.

The greatest number of experiments on the problem of choosing the initial clearances has been devoted to the fitted assembly consisting of shaft and bearing. The intensity of work on this question is a result of the direct effect of this clearance on the wear resistance of fitted parts and the life of the engine as a whole. Test stand and road tests have shown that the minimum wear of main crankshaft journals and crankpins and their corresponding inserts takes place with initial clearances in the range 0.03 to 0.08 mm and 0 03 to 0.07 mm, respectively. Studies have shown that smaller or larger clearances cause premature fatigue-related spalling and chipping of the working layer of the bearing inserts, arising either as a result of contact friction or from the increase in the dynamic load on the bearing inserts, respectively

The optimum range of initial clearances in the fitted assembly camshaft journal - bushing is also 0.03 - 0.07 mm. The effect of the operation of other parts of the valve - camshaft mechanism on their resistance to wear also depends to a significant degree on the values of the initial clearances in the fitted assemblies involved. Thus, when the clearances in the pair consisting of the guide bushing and the inlet valve are increased from 0.03 to 0.15 mm the average indices of oil burning in M-20 and GAZ-69 engines increase from 57 to 117 g/hr, and in GAZ-51 engines from 161 to 302 g/hr, i.e., oil burning almost doubles when the clearance is increased to 0.12 mm. In Table 10 actual current values of clearances are shown, along with optimum values found by workers in scientific research laboratories, for certain fitted assemblies of engine parts.

Engineering Methods of Increasing Engine Life

The technological possibilities of lowering engine wear and increasing engine life have not only not been exhausted up to the present, but are not well enough understood. Despite the large amount of research carried out in this

direction, there are no well-founded recommendations for assigning initial parameters of surface quality, sufficient attention has not been given to the influence of processing methods on the wear resistance of surfaces, and there are no generalized recommendations as to methods and conditions of factory running-in of engines. Particular inconsistencies are seen in the setting of microgeometries of the friction surfaces of engines. All this has pointed out the need for the research at the Gorki Motor Vehicle Plant in which, in all, over 60 engines of various models from the Gorki Motor Vehicle Plant and the Zavolzhsk Motor Plant were measured to determine the single effect of initial microgeometry on wear.

Table 10.

Fitted friction surfaces of parts	Clearances from design drawings, mm				Optimal values of clearances of GAZ and ZMZ engines, mm	
	Flathead GAZ engines		Overhead valve ZMZ engines			
	from	to	from	to	from	to
Cylinder - piston skirt	0,006	0,030	0,000	0,024	0,012	0,024
Cylinder - piston head	0,340	0,430	0,275	0,375	0,200	0,300
Upper piston groove - piston ring	0,050	0,082	0,050	0,082	0,050	0,080
Piston - wrist pin	−0,0025	0,0025	−0,0025	0,0025	−0,0025	0,0025
Connecting rod bushing - wrist pin	0,0045	0,0095	0,0045	0,0095	0,0045	0,0095
Main bearings	0,026	0,083	0,026	0,083	0,0[illegible]0	0,080
Connecting rod bearings	0,026	0,077	0,026	0,077	0,030	0,070
Guide bushing - inlet valve	0,030	0,077	0,050	0,097	0,030	0,070
Guide bushing - exhaust valve	0,065	0,107	0,075	0,117	0,065	0,100
Openings in the block for the tappet	0,012	0,024	0,015	0,033	0,006	0,012

The microgeometries of almost all the basic friction surfaces of the parts of the cylinder - piston group and the crankshaft - connecting rod and valve - camshaft mechanisms were measured. The measurements of the smoothness of the friction surfaces were made with a KV-7 profilometer, type 740 (built at the Gorki Motor Vehicle Plant) connected to a MPO-2 oscillograph, and also by a 201 profilograph - profilometer. Parts from 20 GAZ-51, GAZ-69, GAZ-21 and GAZ-13 engines were measured after having been run-in in 100-hour test stand

tests, in order to determine the optimal values of smoothness of the friction surfaces, with respect to running-in.

From these measurements it was established that, outside of the initial values of smoothness stipulated by the upper limit of the plant specifications and GOST 2789 - 51, and differences in engine models, the parts acquire a new microgeometry which is optimal from the point of view of surface conditions, under favorable conditions of running-in (Fig. 26). These new values, however, still cannot be recommended as initial values, since in setting smoothnesses of surfaces of parts it is customary to also take into account the length of running-in, the subsequent wear resistance of the fitted assembly, and the economic expediency of the given values under production conditions.

All these indices together determine the best value of roughness to be taken as a basis for prescribing the microgeometry of the parts.

With the aim of determining the character and dynamics of the running-in properties and wear resistance of the parts, 40 samples of models of GAZ-51, GAZ-69, GAZ-21, and GAZ-13 engines were subjected to 100-hour and 400-hour tests under loading, and three GAZ-51 engines and four GAZ-12 engines were subjected to long road tests on vehicles. Friction pairs with various conbinations of surface smoothness were selected for the various engines. Thus, the most smooth cylinders were matched with the smoothest, medium, and roughest pistons; and cylinders of medium smoothness were also matched with the smoothest, medium, and roughest pistons; and so on, for all the parts friction surfaces under study. The condition of the parts friction surfaces of the engines was evaluated after 45 min and after 25, 80, 100 and 400 hours of operation on the test stand, and after service mileages on vehicles of 35 and 75 × 10^3 km.

The average results of all the test stand and service tests are plotted and generalized in the diagrams of Fig. 27. The left end of each of the plots corresponds to the initial values of the microgeometry of the parts; and these change in the course of the testing of the engines. The cross-hatched zone characterizes the values of microgeometry which, other conditions being equal, guarantee good running-in of the parts surfaces surveyed. The curves located above and below the cross-hatched zones designate those microgeometries in which, in a number of surfaces, sources of scoring which were smoothed away in subsequent operation of the fitted assembly were present. In certain cases these caused high wear of the engines. Specifying initial measured values of microroughness lying beneath the cross-hatched zone is not economically justified, even when scoring is not present, since with further operation not only improvement but also deterioration of the smoothness in comparison to the initial values may be observed.

Analysis of all the above diagrams, despite their approximate nature which is connected with the processes of disassembly and assembly of the engines, makes it possible to conclude that the short duration running-in at the factory achieves only small progress toward the microgeometry of the parts which is

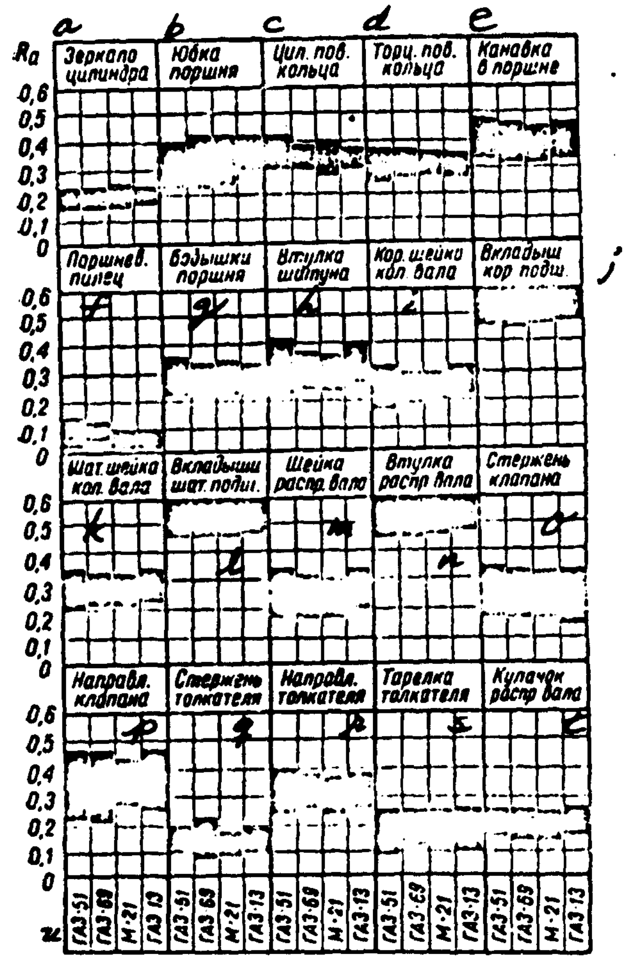


Fig. 26: Optimal Microgeometry of Parts of Engines Produced at the GAZ and ZMZ -- Values Reached in the Running-In Process

Key: a = Cylinder surface
b = Piston skirt
c = Cylindrical surface of ring
d = End surface of ring
e = Piston groove
f = Wrist pin
g = Piston boss
h = Connecting rod bushing
i = Main crankshaft journal
j = Main bearing insert
k = Crankpin
l = Connecting rod bearing insert
m = Camshaft journal
n = Camshaft bushing
o = Valve stem
p = Valve guide [bushing]
q = Tappet rod
r = Tappet guide [bushing]
s = Tappet head
t = Cam
u = GAZ-51, etc.

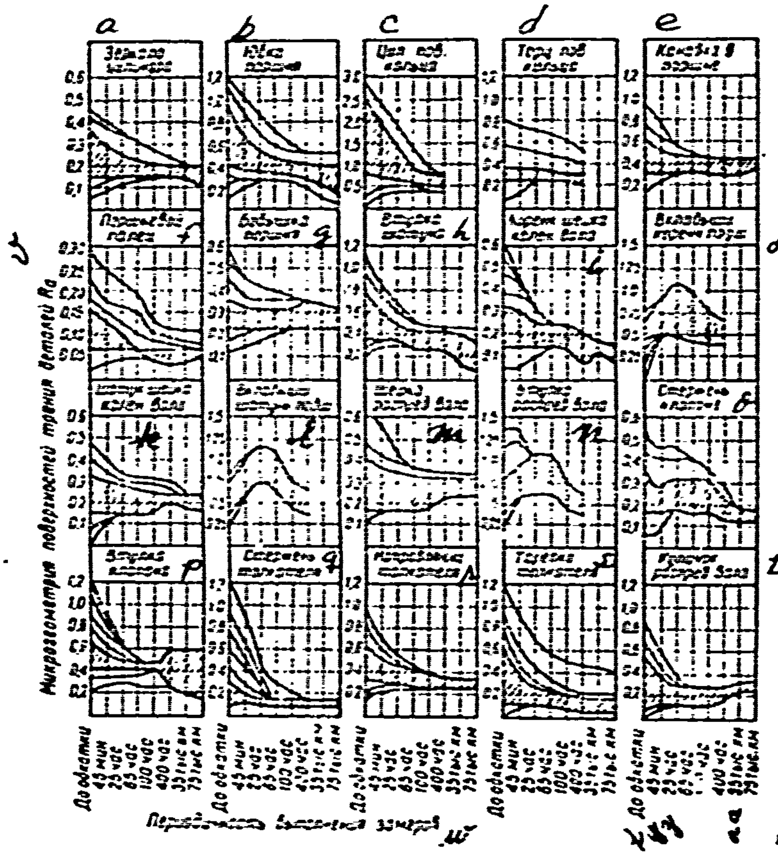


Fig. 27: Variation of the Microgeometry of Parts of Engines Produced at the GAZ and ZMZ -- In the Process of Test Stand Tests, and During Service on Vehicles

Key: a - t = same as Fig. 26
v = Microgeometry of friction surfaces of parts, R_a
w = Period of measurement
x = Before running-in
y = 45 min
z = 25 hr
aa = 35,000 km

optimum from the point of view of breaking-in. In most cases the optimal microgeometry is reached after completion of the microgeometric running-in of the friction surfaces of the parts. In the absence of scoring, grooves, and other defects it did not seem possible in the course of the investigations to determine the effect of initial microgeometry of the parts on the initial and settled wear. High wear levels occurred only in extremely smooth or extremely rough surfaces, as a result of scoring. The limits of initial roughness of parts surfaces found from the research to be optimum from the point of view of break-in, wear, and economy are given in Table 11.

Table 11

Поверхность трения деталей u	Допустимые значения v				Средние оптимальные значения Ra aa	Рациональные значения bb	
	по ГОСТу w		по инструкции x				
	№ ГОСТа y	Ra	Ra	класс и разряд z		Ra	класс и разряд
a Зеркало цилиндров	655—52	0.32	0.32	9а	0.16—0.24	0.16 0.40	9в—9в
b Юбка поршня	865—54	0.80	0.63	8а	0.24—0.40	0.40—1.0	7б—8б
c Цилиндрическая поверхность кольца	846—48	5.0	3.2	5	0.32—0.48	0.80- 2.5	6а—7б
d Торцевая поверхность кольца	846—48	0.63	0.50	8б	0.24—0.32	0.16—0.40	8в—9в
e Канавки в поршне	855—54	1.25	0.63	8а	0.32—0.48	0.32—0.63	8а—8в
f Поршневой палец	776—54	0.125	0.125	10б	0.04—0.08	0.08—0.16	10а—10в
g Бобышка поршня	865—54	0.63	0.40	8а	0.24—0.32	0.24—0.40	8а—9б
h Втулка шатуна	845—54	0.63	0.63	8а	0.24—0.40	0.40—0.80	7в—8в
i Коренная шейка коленчатого вала	4669—54	0.32	0.20	9в	0.16—0.32	0.16—0.32	9а—9в
j Вклад. корен. подшипников	—	—	—	—	0.48—0.63	0.32—0.63	8а- 8в
k Шатунная шейка коленчатого вала	4669—54	0.32	0.20	9в	0.16—0.32	0.16—0.32	9а—9в
l Вклад. шатунных подшипников	—	—	—	—	0.48—0.63	0.32- 0.63	8а - 8в
m Шейка распределительного вала	8007—56	0.32	0.32	9а	0.16—0.32	0.16—0.40	8в- 9в
n Втулка распределительного вала	—	—	—	—	0.48—0.63	0.32—0.63	8а—8в
o Стержень клапана	1287—57	—	0.20	9в	0.16—0.32	0.16—0.40	8в—9в
p Направляющая клапана	3785—57	2.5	0.63	8а	0.24—0.48	0.40—0.63	8а—8б
q Стержень толкателя	1286—57	0.50	0.20	9в	0.08—0.16	0.08—0.32	9а—10в
r Направляющая толкателя	—	—	0.63	8а	0.24—0.40	0.32—0.63	8а—8в
s Тарелка толкателя	1286—57	0.50	0.16	10а	0.08—0.24	0.16—0.63	8а—9в
t Кулачок распределительного вала	8007—56	0.56	0.63	8а	0.16—0.24	0.16—0.63	8а—9в

Key: a - t = same as Fig. 26
u = Friction surface of:
v = Allowable values
w = according to the GOST
x = according to the [plant] specifications
y = GOST No.
z = class and division
aa = Average optimal values of R_a
bb = Efficient values

Particular attention at the Gorki Motor Vehicle Plant has been given to the study of the effect of initial macrogeometry of the parts on the technological condition and the life of engines. Thus, over the last 10 years more than 500 engines of various GAZ and ZMZ models have been studied along these lines, with determination of the initial and subsequent macrodeformations by ordinary micrometry, aided by the method of incised holes (UPOI device) and also with the use of an MPG-3 macroprofilograph.

In studies of cylinders and pistons the effect of macrodeformation was evaluated by the first two methods as well as by indirect methods -- from the oil burning and gas blow-by.

Macroprofilography was performed on wrist pins and openings in the piston bosses and in the connecting rod bushings, and also on main journals of the crankshaft and supporting journals of the camshaft.

In this, holes of a set depth were preliminarily cut out in a number of parts, to enable following the magnitude and character of wear of the studied surfaces in subsequent measurements and comparisons of macroprofilograms. The method of this type for evaluating wear was developed in collaboration with co-workers L.A. May, V. N. Komissarzhevskaya and A. E. Isakov of the NIITAvtoprom. The results of highway tests of vehicles, test stand tests of reliability according to GOST 491 - 55, and accelerated test stand tests with artificial admixture of dust to the air and oil were used to evaluate the effect of initial shape error of parts on their subsequent wear.

The cylinders of automotive engine blocks were subject to the most deviation from circular shape, because of the complex casting configuration which they have and their insufficient rigidity. The limiting value of ovality of the cylinders given in the design drawings, 0.025 mm after assembly and engine break-in, is frequently exceeded, causing increased oil burning and gas blow-by. The increase of these indices causes a sharp dislocation of the heat balance of the engine, drying of the oil film on the cylinder walls, and, in the final analysis, more intense wear of the cylinders and piston rings. Cases have often been noted in which an initial ovality of the cylinders above 0.03 mm shortens engine life by over 1.5 - 2 times as a result of progression of the effect with continued operation.

The studies showed that an initial ovality of cylinder sleeves of GAZ-21 engines of over 0.04 mm progresses to 0.10 - 0.12 mm at the end of 400 hours' operation under load, while for an initial ovality of up to 0.025 mm, specified in the requirements of the design drawings, the subsequent ovalization usually does not exceed 0.05 - 0.06 mm. Methods aimed at increasing the stability of the initial geometric parameters of cylinders in engines were developed at the Gorki Motor Vehicle Plant and the Zavolzhsk Motor Plant; of these the most significant was the use of artificial "aging" of the stock pieces.

The introduction of this and other measures, however, is only a one-sided solution to the problem, since up to the present the motor vehicle plants have not reliably furnished piston rings with the proper geometry. This has led to an increase in the local clearance between the ring and the cylinder surface, causing increased oil burning and gas blow-by.

Macrogeometric deviations in the piston skirt have a deleterious effect on its running-in to the cylinder and sometimes are the source of scoring. This points to the need to set higher standards for the machine tooling of the piston skirt and to increase its rigidity, and to put into production pistons with Invar inserts. The most frequent deviations under production conditions are the macrogeometric deviations of the grooves in the piston underneath the piston rings. These chiefly amount to the deviations from flatness and from perpendicularity of the end surfaces of the grooves to the axis of the piston.

They prevent normal operation of the piston ring - groove fitted pair. Thus, gradual carburization, gumming up, and breaking of the piston rings occurs.

In contrast to cylinders and piston rings, the fitted assembly consisting of the wrist pin, the piston boss, and the connecting rod bushing does not limit the reliability or life of GAZ and ZMZ engines; and this book will not treat the relations between wear in this fitted assembly and the initial shape deviations of the parts which have been discovered. The most interest is commanded by the dependence of wear resistance of the crankshaft journals on initial shape errors.

Analysis of recorded macroprofilograms enabled the conclusion that the initial ovality of the main journals in most cases progresses as the engine tests proceed; the large axis of the oval is most often oriented in the direction perpendicular to the axis of the keyway for the end bearings, and with a definite angular displacement with respect to the rotation of the shaft for the middle main journals. In all cases it was noted that as the initial out-of-round of the shape of the journals was increased, in addition to an increase in journal wear the conditions of operation of the bearing inserts deteriorated, leading to an increase in contact stresses, spalling, and chipping of their working layer. Special observations of the operation of 250 engines of various models established that it is advisable to decrease the tolerances for ovality, conicity, and saddle-shapedness of the crankshaft journals from 0.01 to 0.006 mm. By doing this it is possible to extend the period of operation of bearing inserts 1.5 - 2 times without the appearance of sources of spalling and chipping of their working surfaces. The initial barrel-shapedness of the journals is completely inadmissible; it causes the development of scoring of the inserts during the running-in process. The wear along the straight cylindrical edges of the main crankshaft journals in most cases proceeds nearly uniformly, as a function of the initial deviation from true shape.

The maximum wear values occur on both sides adjacent to the zone of the oil groove in the inserts. This pattern of maximum wear is explained by the expulsion of wear products from the oil groove and the embedding of these in the neighboring zones.

In addition to the above-enumerated parts, the supporting journals of the camshaft of various models of GAZ and ZMZ engines were subjected to analysis of the effect of initial macrogeometry on subsequent changes and wear.

It was found that the change in the form of the out-of-round of the supporting journals before and after engine operation was insignificant. The initial deviations from straightness in the shape of the supporting journals of the camshaft determine the character of subsequent shape variation and the magnitude of the wear. In analogy with the data on crankshaft journals it should be noted that errors in the shape of the supporting journals of the camshaft have a non-negligible effect on the quality of running-in and the level of wear of the bushings; accordingly, it is also desirable to limit the

tolerances for initial deviations in the supporting journals to 0.006 mm. On the basis of the mentioned research and a number of other researches it was found to be advantageous to reconsider the tolerances for initial deviations in the shape of certain parts (Table 12).

Table 12

Initial shape deviation	Allowable value, mm	
	in design drawings	recommended
Ovality of cylinders	0.025	0.020
Conicity, ovality, and saddle-shapedness of crankshaft journals	0.010	0.006
Barrel-shapedness of crankshaft journals	not specified	forbidden
Conicity, ovality, and saddle-shapedness of camshaft journals	0.010	0.006

In addition to the above, a very serious engineering factor affecting engine wear is the method of final mechanical machining of the friction surfaces of the parts. A large number of research reports have been published which were devoted to the study of this interrelationship, with other micro- and macrogeometric parameters being equal. Of the most recent work in this field the application of diamond honing of the cylinder walls of automotive engines to replace the honing with abrasive bars used previously, is of interest. The replacing of the silicon carbide or synthetic corundum by granules of synthetic diamond does not in principle change the physical bases for metal removal in honing, but it improves the quality of the machined surface somewhat. The research was carried out at the Gorki Motor Vehicle Plant and the Kiev Institute of Hard Materials. Thirty engine blocks of GAZ-51 engines were prepared for the study with cylinders honed by diamond and by abrasive hones. The honing of the cylinders was carried out directly under factory production conditions.

K-35 ST2K bars were used for the rough abrasive honing, and KZM 28SM1K bars were used for the smooth honing; and ASP-10 and ASM-28 bars, respectively, were used in the diamond honing. It was found in the course of the machining of these cylinders that the synthetic diamond bars are 56 - 66 times more durable than the abrasive bars. The quality of the machining of the cylinders was evaluated from the micro- and macrogeometries of the surfaces, as well from the physical condition of the surface layers of the metal.

In contrast to the surfaces honed with the abrasive bars, which showed traces of the movement of the separate grains of the instrument and striated indentations with respect to the lengthwise straight dimensions of the cylinder surface, the surfaces which had been honed with the diamond bars were characterized by uniformity and the smoothing over of irregularities. Tests established the greater stability of the micro- and macrogeometries of cylinders, pistons, and piston rings after diamond honing; cylinder wear was 13 - 15 microns less, piston skirt wear was 3 - 5 microns less, and wear of the upper chromed piston rings was 40 - 50 microns less. There are other characteristic examples of the effect of methods of smooth machining of surfaces on subsequent wear. Thus, in laboratory tests of engines in collaboration with the NIITAvtoprom it was established that certain processes which are inherent to high intensity polishing lead to the development of a damaged defect layer on the parts surfaces which has a deleterious effect on attrition and shock, and lowers the wear resistance of the parts. Thus there is a need for a technological operation to follow polishing which can remove this layer without distorting the geometry of the surface and which can provide the required degree of smoothness The co-workers V. N. Komissarzhevskaya and A. E. Isakov of the NIITAvtoprom proposed microfinishing with removal of the defect layer as such a post-finishing operation. These methods far from encompass the wide technological possibilities for increasing wear resistance of engine parts; these are numerous and widely discussed in publications.

The final technological operation in engine manufacture is running-in, in which the friction surfaces of the parts are smoothed and residual particles of abrasive are cleaned away, and the quality of the seals and the performance capability of the assembled engine are tested. Under conditions of temporary large-scale serial production the running-in of the engine is completed quickly. The duration depends mainly upon the degree of technological sophistication of the enterprise. The higher it is the less time is spent on this process. This is why 5 - 10 times more time is spent in running-in of engines in vehicle overhaul plants -- because the parts in overhauled engines under existing methods of overhaul require a more intensive initial running-in. A great deal of research has been devoted to problems of choosing the conditions of short-time factory running-in and the effect of these conditions upon engine wear and engine life.

As a result of all this research it can be considered settled that the effect of various conditions of factory running-in of engines on subsequent engine life arises mainly in gross violation of the regulations for short-time running-in. Under these regulations extremely large or too-small speeds and loads are not permitted to be applied to friction surfaces of parts which have not been run-in. Thus, premature wear in the cylinders has more than once been artificially induced due to running-in of the engine at high rpm immediately after starting.

When new engines are broken in at rpm's lower than 500 - 600, the lubrication conditions of the fitted parts are markedly inferior, and the wear of the crankshaft bearings is high. The viscosity, lubricity, and cooling

capacity of the lubricating oil have a significant effect on the quality and duration of running-in. Oil with too low viscosity promotes scoring and extreme initial wear of the fitted assemblies. This later causes high service wear. The addition of appropriate additives to such an oil normalizes the process of running-in and prepares the engine for receiving the loads encountered in service. Oil with high viscosity retards the process of initial running-in and sometimes lowers its quality, as a result of the inferior penetrability, detergency and cooling capacity of high viscosity oil.

In order to guarantee the proper running-in of fitted assemblies it is necessary to determine the optimal and efficient sets of conditions for running-in individually, for each engine model, taking into account not only design peculiarities but also technological ones pertaining to that engine. Thus, for GAZ-20 and GAZ-51 and their modifications it was found at the Gorki Motor Vehicle Plant that only hot running-in at idle is expedient. For engines from the Zavolzhsk Motor Plant in the period when the new models were adopted it was found necessary to have a preliminary cold running-in. The lack of sufficiently comprehensive computational methods of assigning sets of conditions for running-in makes it necessary to solve this problem empirically. In this process, the optimal conditions of running-in for each engine model are determined first, and then the efficient conditions. The optimal conditions are those which guarantee the desired quality of the initial running-in of the friction surfaces of parts in the engine.

The efficient conditions of running-in, on the other hand, also make provision for the minimum cost of time and resources on the running-in of parts under production conditions. From existing methods of evaluating the quality of initial engine break-in under various sets of conditions and additives to the oil, the break-in conditions for GAZ and ZMZ engines which are presently most suitable have been established.

The maximum amount of iron found in the oil in the minimum time has been taken as the criterion of the intensity of running-in here.

Currently at the Gorki Motor Vehicle Plant preparations are being made to introduce into the production process engine break-in with "Industrial-20" oils with DF-11 additive, containing 10% sulfur and 5% phosphorus and zinc. This additive is added to the oil to the extent of 2.5 - 3%; its various components provide antioxidant and antiscoring properties for the parts friction surfaces.

Operational Methods of Increasing Engine Life

There is a whole range of approved methods in the arsenal of ways and means of increasing engine life under conditions of vehicle service. They are connected with conditions of starting of engines where the vehicles are stored out of doors, with the scheduling of periods of oil changes and filter cleaning, with the use of the proper types of oil and gasoline, with timely shifting of

the transmission in the driving of the vehicle, and with provision for the required conditions for the engine in wintertime.

These and many other methods are dealt with in detail in the literature; nonetheless, the operational possibilities for extending the service life of engines are far from having been exhausted.

Some of these possibilities relate to the initial period of operation of engines, in the process of which the preparation for receiving operational loads is effected. This kind of preparation period is inherent to most models of automotive engines, which, as a result of the specific conditions of continuous mass production in their manufacture, undergo only a brief factory running-in.

The break-in period of an automotive engine requires particular care, since in this period scoring and premature wear of the friction surfaces are particularly likely to develop, as a result of the increased specific pressure in the fitted parts assemblies, and the instability of the clearance dimensions and of the integrity of the oil film. Repeated tests have shown that full loading of an engine directly after factory running-in leads to cylinder wear equivalent to $40 - 50 \times 10^3$ km of vehicle travel, after only 100 hours of testing in accordance with plant engineering specifications. The engine break-in period on the vehicle is over in, on the average, $2.5 - 3.5 \times 10^3$ km of vehicle travel. In practice, a limiting plate is sometimes inserted between the carburetor and the intake manifold in order to prevent the possibility of overloading of an automobile engine which has not yet been broken in.

The diameter of the flow opening of such a plate is chosen experimentally with the idea of limiting the load on the parts to, on the average, 25 - 35% of the maximum load acting upon the part in a fully broken-in engine. Limiting plates are not usually installed in truck engines, because they have governors which limit the rpm. From visual observation through a transparent wall in the mixing chamber of the intake manifold, it was determined for the process of mixture formation in the operation of four- and six-cylinder engines that decreasing the flow cross section not only decreases the amount of gasoline - air mixture entering the manifold, but it also changes the quality of the mixture due to the dropping out of liquid phase fuel.

This is attributed to the increase in the aerodynamic resistance in the intake system and to the development of stagnant zones which lower the speed of the oncoming mixture, particularly in the operation of engines with low crankshaft rpm; and these zones also have a negative effect on the uniformity of distribution of the mixture among the cylinders. As a result, the combustion process deteriorates, gasoline sweeps away the oil film from the cylinder surface, and carbon deposition in the combustion chamber and on the piston heads is increased. Increased carbon deposition, as is the case with other deposited sludge and encrustations, is known to damage heat transfer in the engine, promote burn-through of pistons and piston rings, and, in the final analysis, sharply shorten the service life of the engine before major overhaul.

A group at the laboratory of the Gorki Motor Vehicle Plant has proposed limiting the load on automobile engines by limiting the rotation angle of the throttle valve with the aid of a stop screw.

In comparison with a limiting plate, at the same rpm, torque, and effective power, this method resulted in a lowering of the specific gasoline consumption of 4-cylinder GAZ engines by 26 g/effective hp/hr, and that of six-cylinder GAZ engines by 11 g/effective hp/hr, and the reduction of scale formation by, on the average, 5%. However, it is preferable to totally eliminate any limiting of the mixture feed and to carry out a proper break-in, because it is dangerous to drive an automobile for the first $2 - 3 \times 10^3$ km of its running life with speeds and loads limited. This [sic] results in a lowering of scale deposits in this initial period by 20 - 25%. It is one of the effective methods of increasing engine life in the initial period of service. Not only speed and load conditions, but, overridingly, thermal conditions of operation exert a significant effect on future wear of engines.

A number of studies have been devoted to problems of optimum thermal conditions from the point of view of engine life under service conditions on vehicles. Thus, according to the research results of L. Dem'yanov, lowering the oil and water temperature from values of 75°C to 50°C on a GAZ-51 engine -- other conditions being equal -- causes overall wear to increase by about 1.6 times, and lowering the temperature to 25°C results in an increase of 5 times. There are other data which confirm the effect of the thermal state of the engine on wear.

On the basis of these data at present the problem of maintaining the required thermal conditions in the engine is in principle solved by the use of thermostats and louvers in the cooling system and fans which can be cut out. But these design solutions are sometimes not enough, and additional measures are needed to maintain the necessary thermal conditions. Thus, on the basis of studies carried out by Yu. M. Panov of the thermal state of an engine under winter and summer conditions of service on a UAZ-450 vehicle in the Gorki and Ivanovsk regions it was determined that when the temperature of the surrounding air is below -30°C, beside complete protection of the louvers it is necessary to cover the engine with heating blankets. In the same studies it was found that in order to lower wear after starting of the engine it should be run at idle and medium rpm of the crankshaft to achieve warm-up until the water in the radiator is around 40°C. Only after this should the vehicle be put into motion in low gear, and significant increase in the loading of the vehicle should be avoided until the temperature of the cooling fluid reaches 80 - 90°C.

The question of the mechanism of engine wear during starting cannot be regarded as being well understood up to the present. The available experimental data connect substantial wear in the start-up process of engines with the variation of the operating conditions of the cylinders and piston rings under the influence of the sweeping away of the residual oil film by the unvaporized part of the fuel and condensed moisture, with the sharp thermal deformation of the parts, etc. Many scientists believe that start-up wear has its origin in corrosion. Studies

of this allow one to hypothesize that such wear has more of a molecular mechanical character than a corrosion character, and is chiefly caused by insufficient lubrication in the starting of a cold engine. In the field of lowering start-up wear, not only the search for methods of quick engine warm-up but also the increase in the stability of the viscosity and other physical and chemical properties of the lubricating oil will evidently be of decisive importance. In many respects it is the properties of the oil which ultimately determine the character and the dynamics of wear, since it is the oil which substitutes liquid, semi-liquid, or, as the case may be, boundary friction for dry friction, while removing heat from the working surfaces of the parts. The resistance of the oil to being squeezed out from the gaps between the parts, its resistance to aging, and its anticorrosion properties are among those parameters which to a large degree determine parts wear, in addition to the viscosity of the oil and its chemical and physical stability. Researchers have noted that it is normal to have a 3 - 5 times variation in the wear of cylinders of an engine depending on the properties of the lubricant used.

At present particular effort is being devoted to the problem of the application of lubricating oils: depending on the purpose for which the oil is intended, additives are being incorporated which increase the strength of the oil film, decrease the scale formation, or perform multiple functions. The physical and chemical properties of the gasoline used also have a major effect on engine wear under service conditions. Among the basic qualities of gasoline which can be analyzed and which affect engine life are the fractional makeup, the chemical stability, and anticorrosive and antiknock properties. The effect of these qualities on the service life of engines is the subject of special research and measurement, and in this bock this problem is discussed mainly with reference to the literature sources.

On the basis of studies of the effect of the final distillation temperature of the gasoline upon wear it was noted that the use of gasoline with a final distillation temperature of 170 - 180°C lowers engine wear by 35 - 48% in comparison with the use of gasolines with a final distillation temperature of 218°C. Gasoline with an extremely light fractional composition no longer gives a substantial positive effect. Increasing the content of high-boiling fractions, on the other hand, causes strongly increased oil dilution.

The substantial effect which higher final distillation temperature has upon wear can be attributed to the sweeping away of oil from the walls of the cylinder and to general dilution of the oil in the engine system.

The antiknock properties of the gasoline have just as strong an effect on the service life of the engine.

In the various engine models the knock modes of operation usually develop at 100% load and medium crankshaft rpm, apart from the dependence upon engine design features such as compression ratio, combustion chamber shape and cylinder diameter. Under service conditions such knock modes correspond to rapid acceleration of the vehicle or uphill movement on a smooth road under high load. The

development of knocking is caused by the use of gasolines with octane number which does not satisfy the requirements for the given engine model. Operation of the engine with knocking is accompanied by a sharp increase in the maximum pressure, combustion temperature, and shock wave effects, resulting in destruction of the oil film on the cylinder walls, corrosive action of the reactive products of partial oxidation, intensive cylinder wear, sticking of the piston rings, chipping of the bearing inserts, etc.

A number of studies have been carried out which were aimed at determining the effect of knocking on cylinder wear, including [some] at the Scientific Research Institute of Vehicles and Engines at the NAMI, in conjunction with the Institute of Machinery Science. The engine involved was that of the ZIL-120. As a result it was found that average wear in the upper region of the cylinders under conditions of knocking was more than 2 times as high and the average maximum was more than 3 times as high as wear under conditions of operation without knocking.

Operation of the engine with early spark advance without knocking also causes increased wear in comparison to wear with retarded spark advance, other conditions being equal.

Experiments performed at the Central Engine Laboratory of the Gorki Motor Vehicle Plant also established the appreciable influence of knock modes of engine operation upon temperature elevation of cylinders and pistons, which in some cases caused scorching of the latter. Thus, when the compression ratio of a GAZ-21 engine is raised from 6.6:1 to 7.5:1 in operation on B-70 gasoline with an octane number of 70 the wall temperature of the cylinders increases on the average by 20 - 25°C, and that of the piston heads by 55 - 60°C. Under knock-free operation of the same engine on B-91 gasoline the temperature of the cylinder walls and pistons fell to a value corresponding to engine operation at a compression ratio of 6.8:1. Engine knock can appear under service conditions not only as a result of the use of gasoline of the wrong octane number, but most frequently as a result of changes in the composition of the fuel mixture, scale formation on the pistons and the cylinder heads, changes in the spark advance, variations from optimal thermal conditions, etc.

A. Serov carried out special studies to determine the effect of spark advance and fuel mixture composition upon wear. A GAZ-51 engine was tested with subsequent wear evaluation by the iron-in-oil method. The tests were conducted at a constant 16.5 hp, corresponding to 2000 rpm, and with a coefficient of excess air α equal to 1.

According to the data of the author, the wear as a function of the spark advance angle is minimum at an angle of 20°, based on tests over the range from 0 to 40°. Wear increased both when the spark advance angle was increased and when it was decreased. The effect of the coefficient of excess air was evaluated within the range of α from 0.6 to 0.2, at constant load, rpm, and spark advance angle (16.5 hp, 2000 rpm, and 30°). The results of the tests indicate that the maximum engine wear occurs at a mixture composition in the range α = 1.0 - 1.15, and tends to decrease with richer or leaner mixtures. The loads upon the engine parts and the speed of parts with respect to each other also

significantly affects the wear of their operating surfaces. The effect increases as the intensity of the thermal operating conditions of the engine decreases.

The test results indicate that the wear is directly proportional to the load, and is a power function of rpm. These relations are explained by differences in the friction conditions of fitted parts assemblies, determined by the pressures involved in and the speeds of their motion relative to each other under different conditions of lubrication and temperature. Thus, the wear of the working surfaces of the cylinders and piston rings in a certain range increases proportionally to gas pressure and to the rate of rotation of the crankshaft, whereas wear and tear of the working surface of the piston skirts is determined mainly by rpm, and depends very little upon the pressure of gases on the pistons. Wear of the crankpins and crankshaft main bearings depends both on the speed and on the load. But increasing rpm by 10% increases the load on the bearings by about 20%, since there is also a power function relation between these parameters.

In the area of the effect of the rate of crankshaft rotation upon the wear of friction surfaces the research carried out by M. S. Beliaskiy is of notable interest. He recommended a minimum allowable crankshaft rpm, with a direct transmission, of 1600 - 1700, in order to increase engine life of flathead GAZ engines.

Overall, one may conclude that increasing crankshaft rpm affects overall engine wear more than increasing the load. The functional relations between these parameters and the wear resistance of individual parts friction surfaces vary.

Chapter V

Accelerated Tests for Engine Wear and Engine Life

Appraisal of Existing Methods of Testing Engines

In Chapter II of this book methods of evaluating engine wear and engine life were discussed which amounted mainly to choosing means of measuring wear and evaluating engine life according to indirect indices and service properties of parts. These methods and techniques, depending upon their individual features, can be used either under service conditions of the the engines in vehicles, or in highway proving ground and laboratory teststand tests. The service tests of engines for lifetime are based on reporting service lives in vehicles under various service conditions and subsequently processing the data statistically.

The extremely high scatter in the results of observations under engine service conditions makes the evaluation of average lifetime of a given model time-consuming. Therefore service data are more often a means of generalizing and confirming specially designed tests than they are methods of evaluation in and of themselves.

However, sometimes service testing is a means of evaluating certain concrete parameters of engine operation under real and widely varying conditions of service - parameters such as the periodicity of load change, the most frequently employed ranges of crankshaft rpm, changes in the thermal conditions, degree to which steady and unsteady conditions prevail, frequency at which "cold" starts occur, etc. For this kind of a study, aimed at characterizing the operating condition of engines in vehicles, special equipment and apparatuses are necessary. In recent years the use of certain devices developed at the NAMI has been spreading: the RPV distance and time measuring device, a PKU recorder, the measuring device designed by the Design and Experimentation Department of the GAZ, and the modernized version of L. G. Lavrov, the GSKhI [Gorki Agricultural Institute] measuring device, and others. These provide separate and combined readings of a number of parameters which characterize the loading and speed conditions of engine operation.

The laboratory methods amount to proving ground and laboratory test s and tests of engines. The evaluation of engine life under these is performed either from indirect indices or according to the wear resistance of the parts which normally limit the service life of present-day vehicle engines--these being the cylinder walls, piston rings, pistons, and crankshaft journals; and also according to the heat resistance of the pistons and the heads of the exhaust valves. In order to reduce data scatter it is advisable to evaluate engine life in highway tests of vehicles under conditions and on roads which will characterize the service of that type of vehicle. The road tests for engine life were carried out in three basic ways: under vehicle service conditions in transport with constant controls on the observance of the engineering specifications for vehicle use; with artificial loading of the vehicle and trips on general-use roads according to a previously developed testing program; and on proving grounds with courses over special roads of various types and with the use of elevated conditions to speed up testing.

Proving ground tests reproduced to some extent the service conditions of automobiles and engines, but in them the number and time of stops and the number of starts are sharply cut, and there is entirely no correspondence with the unsteady operating regimes and other conditions which are characteristic of service. At the same time, in comparison with service tests, proving ground tests make possible a wide choice of speed and load conditions, make it possible to use single varieties of fuel and lubricating materials (necessary for making comparisons), guarantee identical engine tuning condition, and on the whole substantially reduce the scatter in the test results of automotive engines.

Such tests, however, for evaluating engine life or the effectiveness of various measures for increasing it, take a long time--about 10 to 11 months. Laboratory test stand tests are even further from service tests, but at the same time they make it possible to model any engine operating conditions desired and, the scatter and the wear values not withstanding, they guarantee the comparability of the results with respect to engine life.

Properly chosen conditions of test stand testing for engine life should represent the character and the approximate relations of the values of wear under well defined service conditions. Such requirements make it necessary to set up a number of variants of the conditions of accelelated test stand tests for engine life, to correspond to mechanical, corrosion-mechanical, and molecular mechanical forms of wear and tear, and also to enable the evaluation of the heat resistance of the pistons and the heads of the exhaust valves. Imitation of abrasive wear involved in the mechanical form of wear and tear can be done to advantage by feeding quartz dust to the cylinders and to the crankcase with the aid of special regulated dust feeders. In this type of test engine operation primarily at loads close to service loads and under a nominal temperature regime is specified.

Corrosion wear of the cylinder walls can be represented during engine operation and with frequent starts by circulating cold water, carrying out the tests in a cold room, or by using high-sulfur gasoline at low engine speed conditions.

A high intensity of the molecular mechanical form of wear and tear which can accompany high temperatures can also be attained by operating the engine at high loads and high rpm with moderate cooling. In this it is advantageous to also include cycles of sharply varying load and rpm. The conditions for testing engine parts for heat stability involve sharp increase of the thermal stresses at high sliding speeds of the parts, where the cooling and lubrication systems are not capable of removing the heat from the heated parts. Since burning through of the valve heads often precedes corrosion phenomenon, gasoline with high tetraethyl lead content, which promotes intensification of these processes, can be used.

All the enumerated conditions for accelerated tests and testing of engines for life time and heat resistance of the parts are designed so that after their development they can be applied to new or modernized engine models. Also, for periodic evaluation of the engine life of models in current production it is desirable to have one set of conditions which gives rise to all the above-enumerated forms of wear and tear and is relatively closer to the actual service conditions of engines on vehicles. It should be noted, however, that many researchers are skeptical of the establishment of this form of accelerated test stand testing of engines, and as yet the data from the Gorki Motor Vehicle Plant do not support the possibility of realizing coincident test conditions for mechanical, corrosion-mechanical, and molecular mechanical forms of wear.

At present the laboratory test stand methods of evaluating engine life and freedom from breakdown are set down in legislation for testing engines "for reliability" according to the conditions given in GOST 491 - 55. These, in essence, make it possible to obtain very approximate ideas about the rate and character of parts wear in various engine models; these results are not commensurate with wear in service. Some researchers have noted that the wear of engines in service is two to four times higher than that obtained in the period of test stand testing according to the GOST conditions, and according to our data this figure is three to five times, or more. The tests under the engineering specifications which are used in the plants are even less commensurate with service conditions of operation of the engines. At best, they guarantee full break-in and reveal specific defects of manufacture of parts and in the assembly of subunits, but it is practically impossible to conclude anything from the results of these tests about the wear resistance of the friction surfaces. The data presented in Table 13, which are generalizations from 120 engines, are evidence of the insignificance of parts wear after 100-hr tests of parts under load and the preceding 30-hr running-in according to the conditions of the engineering specifications of the GAZ and ZMZ.

There is practically no wear of the piston rings in the height dimension of the piston grooves along their end faces, in the wrist pins, or in other parts and friction surfaces during the engine tests according to the plant engineering specifications (TU). In Table 14 average wear values are given for some main parts friction surfaces after 400- and 600-hr normal operating condition tests under GOST 491 - 55, along with average wear and engine operation on vehicles with a service mileage equivalent in length to the GOST tests.

Table 13

Parts friction surfaces	Wear after 100-hr test stand tests, mm			
	GAZ-69	GAZ-51 GAZ-63	GAZ-21	GAZ-13 GAZ-53
Cylinder surfaces	8-10	8-10	6-8	
Radial thickness of upper rings	10-15	14-18	12-20	
Piston skirts	11-13	13-15	11-14	
Main crankshaft journals	4-5	3-5	3-4	
Crankpins	3-5	4-5	3-4	
Camshaft supporting journals	2-4	2-4	1-3	

The equivalent service mileages for the engine models GAZ-450, GAZ-51, GAZ-21, GAZ-5? and GAZ-66 are 24,200, 27,000, 29,600, 30,600, and 30,600 km, respectively.

From Table 14 it is seen that the wear of certain friction surfaces, for example the cylinder surfaces, in engine testing under highway conditions sometimes exceeds the wear in the GOST 491-55 tests by two to five times. The ratios expressing the character of cylinder wear in the 100-hr tests of engines according to the current TU, and tests according to GOST 491-55, and in the vehicle runs were all equivalent to the GOST conditions.

The features which characterize service wear of cylinders are: a sharply differentiated peak wear zone in the upper region of the cylinder and abrasive action in its [sic] middle part. Test stand tests of engines are usually characterized mainly by purely mechanical wear of the cylinders, which differs from wear under service conditions. Thus, existing methods of test stand testing are only to a slight degree models of engine life, both quantitatively and qualitatively. This makes it necessary to develop special methods of accelerated engine testing for engine life.

In addition, natural testing of individual subassemblies and parts may be very helpful for preliminary estimation of the effectiveness of various measures for increasing engine service life. The existing basic test conditions for parts and aggregates may be classified as follows, as recommended by R. V. Kugel:

1. Service conditions which most closely reflect real service conditions in the character, value, and frequency of application of loads. Such conditions require testing over a long time period.
2. Conditions with increased frequency of loading, which closely reflect real service conditions in the character and value of the loads, but in which the frequency of application of the loads is increased relative to actual service conditions.
3. Increased load conditions, representative of service conditions in the character and location of action of the loads, but with the loads themselves substantially boosted compared to service loads.
4. Conditions of increased frequency and intensity of loading--combinations of (2) and (3) above, in which the character of service wear is represented [but] over

a shortened time interval.

5. Slow motion conditions, representing testing under normal and increased loads, but reduced speeds which facilitates opportunities for observation.

6. Special conditions which differ sharply from service conditions but, since the results obtained are commensurate, are suitable for comparative testing of subassemblies and parts.

Table 14

	Parts friction surfaces	Engine model			
		UAZ-450	GAZ-51	GAZ-21	GAZ-53 GAZ-66
Wear during test stand tests according to GOST 491 -55, microns	Cylinder (circle of maximum wear)	20-25	25-30	50-55	25-35
	Upper compression rings, [radial] thickness	30-40	45-60	50-75	30-40
	Upper compression rings, height dimension	5-10	5-10	13-20	15-20
	Upper piston grooves, height	5-10	10-15	10-15	17-20
	Main crankshaft journals	7-12	10-15	8-12	6-8
	Crankpins	5-7	15-25	5-7	4-6
Wear during equivalent service mileage under highway conditions, microns	Cylinder	40-50	65-75	55-65	50-60
	Upper compression rings, /radial/thickness	72-170	81-180	59-180	60-180
	Upper compression rings, height dimension	5-12	27-54	45-50	45-50
	Upper piston grooves, height	12-24	13-27	30-37	40-45
	Main crankshaft journals	20-30	30-35	11-74	20-25
	Crankpins	40-45	50-55	6-7	8-15

This classification is suitable for parts of machines in general, and in particular of automotive engines, but in the latter case it is advisable to supplement it with specific features which reproduce abrasive and corrosion-mechanical wear for certain parts. Thus, when a step of natural testing is introduced into the overall test sequence for engine life, a general test diagram will have the form:

Natural testing of parts → Accelerated test stand testing of engines → Proving ground tests of engines in automobiles → Follow-up testing under service conditions

For each of these testing forms a scale factor must be found; it is logical to use service tests of engines on vehicles as a basis for this. Without this the comparability of various forms of tests will be eliminated, it will be impossible to compare experimental data obtained from different tests, and it will become an impossibility to collect, systematize, analyze, and generalize information in the area of increasing engine life.

Development of Methods of Accelerated Test Stand Testing

The study of the effect of various factors derived from design, engineering, and use influences on engine life has made possible certain generalizations which characterize the appearance and wear of basic parts under service conditions:

1. Lengthy engine testing at maximum torque increase the stress conditions of operation and accelerates mechanical wear and breakdown of the parts. Translated into service conditions, such tests correspond to overloading of the vehicle when it is driven under roadless conditions.
2. At increased rpm the inertial and thermal loading of most of the parts increases. Also, at low speeds, below 1,000 rpm, the lubrication conditions of the crankshaft are worsened and increased wear of the journals and bearing inserts is possible.
3. Operation under unsteady conditions with frequent starting and stopping of the engine interferes with the thermal field, reduces the stability of the lubrication of the parts, promotes the entry of liquid phase fuel into the oil, and thus intensifies corrosion-mechanical wear of the parts.
4. Extremely high thermal conditions in the engine can be accompanied by the formation of scoring and seizing of the parts, while engine operation at low temperatures causes corrosion wear of the cylinders and correspondingly high wear of the piston rings.
5. Dustiness of the air entering the engine causes abrasive engine wear, and the effect increases when quartz and feldspar particles are contained in the dust, and it also depends upon the form and size of these particles.

The dustiness of the lubricating oil has a particularly strong effect upon abrasive wear of the crankshaft journals, and also affects the wear of the lower and middle zones of the cylinders.

6. High-sulfur content in the fuel accelerates corrosion wear of the cylinders and piston rings. When tetraethyl lead is present in the fuel the likelihood of piston and exhaust valve burn-through is increased. The use of gasoline with a high final boiling point also promotes increased wear because it washes away the oil from the cylinder walls and it generally dilutes lubricants.
7. When the oil has very low viscosity the oil film loses its strength and shock-absorbing ability. As a result contact friction appears and the molecular mechanical form of wear intensifies. Very high-viscosity oil has inferior penetrability, detergency, and cooling capacity, which also promotes molecular mechanical wear. In addition, operational adjustment of the mixture composition

and spark advance, severity of engine operating conditions, knocking modes, etc. influence parts wear.

The separate and combined action of all the enumerated factors promotes the development of the abrasive, corrosion, and molecular forms of wear. Despite the complexity of modeling service wear of parts under test stand engine test conditions, researchers have today found partial ways of solving this problem. A number of these were taken as the basis for the development at the Gorki Motor Vehicle Plant of a method of accelerated test stand testing for the life times of parts of the cylinder-piston group and the crankshaft-connecting rod mechanism. The practical possibilities of this method encompass the following:

1. Rough determination of the effect of various techniques and modernization steps adopted in the production of engine models upon life times.
2. Preliminary evaluation of the service life of newly built samples of engines in the design stage, by comparison of test results with those of previous engine models.
3. Evaluation of the effectiveness of individual measures developed to increase engine life and wear resistance of particular assemblies and parts. The measurements necessary to develop the techniques where confined to those surfaces which limit the service life of present-day automotive engines--cylinder walls, piston rings, ring grooves in the pistons, and crankshaft journals. Evaluation of the wear in cylinders, piston rings, piston grooves, and all the crankshaft journals was carried out by ordinary micrometry. In isolated cases the wear of cylinders was evaluated also by the method of "cut out holes" using the UPOI-6 device, and by means of indirect indices--oil burning and gas blow-by. In addition to the micrometry, the wear of the main crankshaft bearings was also determined by inscribing holes and comparing the macroprofilograms recorded by an MPG-3 macroprofilograph. The UAZ-450 engine was taken as the basic model for testing and experimentation in the studies. The advantage of this engine for this purpose in comparison to other models from the Gorki Motor Vehicle Plant and the Zavolzhsk Motor Plant consists of its relatively low cylinder wall deformation.

Long highway service tests of UAZ-450, GAZ-51, and GAZ-53 vehicles [sic] were conducted, mainly to evaluate the thermal condition of the engines under various operating conditions on vehicles and to find the most characteristic sets of service conditions. This part of the study was performed by workers in the engine laboratory of the GAZ in collaboration with co-workers of the Gorki Agricultural Institute, in particular the engineer Yu. M. Panov. The measuring device used to evaluate the load and speed conditions of the engines was the modernized version of the RPV device of the engineer L. G. Lavrov, as well as similar devices. In contrast to devices which continuously record a process on tapes, this measurement device makes it possible to conduct a study over a period of long vehicle service mileage. It permits recording the number of engine starts, the duration of operation--overall, under load, and at idle--and also rpm and the angle of opening of the throttle valve vs time, in addition to a large number of indices of the vehicle as a whole and of the transmission.

Chromel-Alumel and Chromel-Copel thermocouples mainly were used to evaluate the thermal condition of the engine, and also MMT-1 thermistors with an ohmmeter. The readings of these were recorded by a portable DC potentiometer, type PP, with a PMT-10 switch. The temperatures of the water and the oil at various points of the cooling and lubricating systems, and that of the exhaust gases, were measured. The temperature of the upper zone of the cylinders was calculated using conversions from test stand tests.

The following facts were established from generalization of the results of road service tests and numerous literature data:

1. The thermal operating conditions of engines in vehicles under service conditions are relatively stabilized in summer and in winter within 10 to 15 and 20 to 25 min, respectively. The engine is started from 30 to 500 times per 1,000 km, depending upon the mode of service of the vehicle.

For vehicles driven over roads of various qualities the engine operates for the maximum period at rpm's in the range 400 - 2,000 and at 50 - 70% load, using 13 - 78% of the maximum power. In engine operation with a 12 - 15% load at 1,000 - 1,200 rpm a temperature of the cooling water in the water jacket of the engine block on the order of 60 - 70°C corresponds to a temperature of the upper cavity of the cylinder walls of around 80 - 90°C. These values are a limit below which conditions favorable to intensified corrosion occur. The latter development promotes washing away of the oil from the cylinder walls by a fuel emulsion. Thus, corrosion wear can be imitated under test stand test conditions by incorporating a significant number of cold starts and by using cold water in the operation of the engine at low rpm and loads not over 15% of the maximum.

2. The imperfect state of contemporary air cleaners does not provide the desired removal of dust from the air entering the engine. From 2 to 14 mg of dust per 1 m^3 of air enters the cylinders of the engine, depending upon the dustiness of the air and the type of air cleaner. The results of a thorough analysis of these data were the basis for some alternative conditions of accelerated test stand testing for engine life which were developed by the author in collaboration with the engineers A. P. Yegorova and Yu. M. Panov. No less than 5 to 8 GAZ-69 and UAZ-450 engines were tested under each of the sets of conditions shown in Table 15. Thus 50 engines were involved in the very first stage of testing, and on the whole, for purposes of development and testing of methods for other models, 85 engines produced by the GAZ and ZMZ were tested.

The selection of the sets of test conditions enumerated in the table was based on the following considerations:

1. Conditions No. 1 are the starting point since test results from a large number of engines have been obtained in the factory under these conditions, in addition to the tests referred to in the table. Such tests are regularly carried out according to the engineering specifications for control testing of the quality of assembly and running-in of parts friction surfaces.
2. Conditions No. 2 were taken as a means of creating conditions which promote the maximum development of corrosion wear of the cylinders via engine operation under partial loads with frequent stopping and starting.
3. Conditions No. 3 are intended to create engine operating conditions of maximum severity from the point of view of temperature stresses and friction, causing high mechanical wear of the parts friction surfaces.

Table 15.

General test conditions	Mode and duration of one cycle		No. of cycles
1) Control testing acc. to GAZ Engineering Specs. Oil change after 50 hr. t_{water} = 70 - 80°C t_{oil} = 75 - 85°C	Idle at rpm = n_{min}, 100% load at rpm = n_N, 100% load at rpm = n_m, 100% load at rpm = 2700,	30 min. 30 min. 2 hr. 2 hr.	20
2) Testing at low load. Oil change after 50 hr. t_{water} = 70 - 75°C t_{oil} = 50 - 75°C	Idle at rpm = n_{min}, 15% load at rpm = 1100, Stop, Momentary stopping each	30 min. 2 hr. 30 min. 15 min.	33
3) Testing at high load. Oil change after 50 hr. t_{water} = 70 - 80°C t_{oil} = 80 - 90°C	100% load at rpm = n_m, 100% load at rpm = n_N, idle at rpm = n_{min} for 15 min every hr.	2 hr. 2 hr.	20
4) Testing with cold water. Oil change after 50 hr., 400 starts. t_{water} = 10 - 15°C t_{oil} = 35 - 45°C	Idle at rpm = n_{min}, 15% load at rpm = 1100, Stop, Momentary stopping each	30 min. 2 hr. 30 min. 15 min.	33
5) Testing with 4 mg dust fed into cylinder per 1 m^3 air, and 50% into crankcase. No oil change. t_{water} = 75 - 80°C t_{oil} = 80 - 90°C	100% load at rpm = n_m, 100% load at rpm = n_N, Idle at rpm = n_{min} for 15 min every hr.	2 hr. 2 hr.	20
6) Testing with 2 mg dust fed into cylinder per 1 m^3 air, and 50% into crankcase. No oil change. t_{water} = 75 - 80°C t_{oil} = 80 - 90°C	100% load at rpm = n_m, 100% load at rpm = n_N, Idle at rpm = n_{min} for 15 min every hr.	2 hr. 2 hr.	20
7) Testing with cold water, plus dust feed as per conditions of (6). No oil change.	Idle at rpm = n_{min}, 15% load at rpm = 1100, Stop, Warmup [sic], 100% load at rpm = n_m, Idle at rpm = n_{min}, 100% load at rpm = n_N.	30 min. 2 hr. 30 min. 15 min. 1 hr. 15 min. 1 hr.	20

4. Conditions No. 4 are derived from No. 2, with testing of the engines without thermostats and with circulation of cold water, in order to intensify corrosion wear of the cylinders.

5. Conditions No. 5 are derived from No. 3, with the feeding of 4 mg per 1 m^3 of air into the cylinders, and 50% of this amount into the engine crankcase. This dust quantity, corresponding to GOST 8002-62, and containing 65 - 95% quartz and other particles, was chosen on the basis of experience in accelerated tests for abrasive wear and tear of tractor engines and was based on fundamental calculations of the volume of incoming air, the crankcase volume, etc.

6. Conditions No. 6 differ from No. 5 in the twofold reduction of the amount of dust fed to the cylinders and the crankcase oil; the aim of this is to make the test stand test conditions approximate real service conditions of automotive engines.

7. Conditions No. 7 are a combination intended to create the conditions to force development of abrasive, erosive, and corrosion forms of wear of the basic parts friction surfaces.

The development of the above sets of conditions for engine testing was carried out on the hydraulic and electrobalance brake stands of the plant engine laboratory. The low water temperature in the engine cooling system for the purpose of intensifying corrosion wear was obtained by carrying out the tests in the fall and winter. In addition, by increasing the transmission ratio from the crankshaft pulley, the output of the water pumps was increased by 3.5 times.

Continuous dust feed to the cylinders was accomplished by using ejection type dust feeders; dust feed to the crankcase oil was intermittent, once per 2 hr of operation. Intensified abrasive wear was achieved by operating the engine without an air cleaner, and in a number of cases also without an oil filter. This technique creates a significant difference between the operating conditions of the engine on the test stand and real service conditions. The desired effect is thereby attained in a shorter time interval, but the character of the wear distribution is in principle retained, as tests have shown.

Table 16 gives the average values of the maximum wear of friction surfaces of the basic parts which limit the service life of engines, from the results of the test stand tests under the different sets of conditions. For comparison, the table includes average values over 8 UAZ-450 engines of parts wear after vehicle service over 60-80 x 10^3 km in the winter and summer, in the middle zone of the European part of the USSR, and also wear after normal-operation tests of the engines according to GOST 491-55.

From analysis of the test results it was established that:

1. The corrosion wear of the cylinders after 100 hr of test stand testing under Conditions No. 4, despite its low value (20-25 micron), was distributed in agreement with the law under which it developed in lengthy vehicle service of the engines. The definite prevalence of maximum wear in the upper zone of the cylinders was noted (Fig. 28).

Table 16.

Таблица 16 [sic]

a Условия и режимы испытаний	b Цилиндры	h Средние значения наибольших износов, мм [sic]: c верхнее кольцо по рад. толщине	d верхнее кольцо по высоте	e верхняя канавка по высоте	f коренные шейки коленчатого вала	g шатунные шейки коленчатого вала
i Пробег 60—80 тыс. км	100—150	250—300	100—200	50—100	25—50	70—90
j 400 час ГОСТ 491—55	20—30	20—50	5—10	5—10	5—10	5—10
k реж. № 1	3—5	15—20	2—5	—	5—7	2—5
реж. № 2	4—7	15—20	2—5	7—12	2—5	2—4
реж. № 3	7—10	15—20	2—3	5—8	2—5	3—6
реж. № 4	20—25	20—30	10—15	7—12	4—7	4—6
реж. № 5	180—210	770—790	150—160	430—460	40—50	60—70
реж. № 6	90—100	340—360	85—100	100—130	25—30	65—75
реж. № 7	80—90	115—125	65—75	120—140	20—25	35—45

Key: a = Test conditions; b = Cylinders; c = Upper ring, with respect to radial thickness; d = Upper ring, with respect to height; e = Upper groove, height; f = Main crankshaft journals; g = Crankpins; h = Ave. values of max. wear, mm [sic]; i = 60 - 80x10^3 km run; j = 400 hr, GOST 491 - 55; k = Conditions No 1 [see Table 15].

Testing of the engines according to Conditions No. 5 caused such wear in the piston rings that not even constant addition could compensate for the lack of oil. Of five engines tested under this set of conditions only two survived the 100-hr test program. The other 3 engines were removed from the test stands after 75 hours because it was impossible to repair them. On the whole it can be said that the abrasive wear of the cylinders resulting from dust addition follows the character of the wear pattern of service wear: there is a certain growth in the middle zone of the cylinders.

2. The absolute value of the wear of the piston rings with respect to radial thickness and respect to height, and also of the piston grooves, was very small in test stand testing for corrosion wear according to Conditions No. 4. In practice it was a little higher than the wear of these friction surfaces in the engine tests according to Conditions No. 2 (low loads without cold water). In tests of the engines for abrasive wear according to Conditions Nos. 5 and 6 the wear of the above mentioned surfaces was comparable to wear after lengthy service, and in most of the cases even exceeded the latter in absolute value. First piston rings which were porous-chromed wore a little less than the lower rings, in their radial thickness. The wear with respect to the height of both piston rings and piston grooves decreased from the top to the bottom ring. This is typical for abrasive wear of parts friction surfaces. In the tests under Conditions No.7 for combined forms of wear, the wear of the piston rings with respect to radial thickness was substantially less than under Conditions No. 6.

At the same time, a certain increase in the absolute value and rate of wear of the piston grooves with respect to height was noted.

3. The wear of the main crankshaft journals and crankpins of the engines, which was tested under Conditions Nos. 5, 6, and 7, was comparable to wear after lengthy vehicle service.

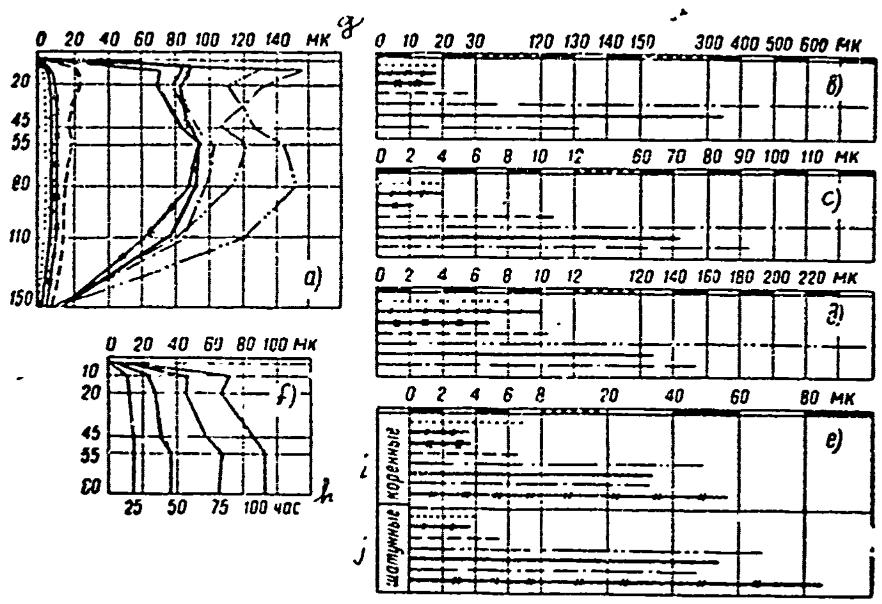


Fig. 28. Wear of Parts of UAZ Engines under Various Test Stand Test Conditions: a -- wear of cylinders; b -- wear of upper rings, with respect to radial thickness; c -- wear of upper rings, with respect to height; d -- wear of upper piston grooves, with respect to height; e -- wear of crankshaft journals; ··· Conditions No. 1; -/-/ Conditions No. 2; -x-x Conditions No. 3; ---- Conditions No. 4; -›,- Conditions No. 5; —— Conditions No. 6; ---· Conditions No. 7; -//- (70-80)x10^3 km vehicle travel; -··· 100,000 km vehicle travel; f -- wear dynamics of cylinder under Conditions No. 6.

Key: g = microns; h = hr; i = main journals; j = crankpins.

Macroprofilograms of the non-straightness and out-of-round of the shape of the main crankshaft bearings which were taken before and after service, and also those taken in test stand tests of engines under conditions imitating abrasive wear confirmed that the character of the wear distributions over the journal surfaces is identical, both for type UAZ-450 engines and for other engine models tested subsequently.

On the whole the tests of 4-cylinder flathead GAZ engines made it possible to conclude that:

1. Accelerated test stand tests for corrosion wear can be used for rough evaluation of the corrosion resistance of cylinders and piston rings of automotive engines, using Conditions No. 4. The low absolute values of the wear obtained by this method make it necessary to continue research aimed at finding more effective means of imitating operational wear due to corrosion.

2. For evaluating abrasion resistance of basic parts and fitted assemblies of the cylinder-piston group and the crankshaft-connecting rod mechanism of the engine, 100-hr and 50-hr versions of Conditions No. 6 can be recommended. Conditions No. 5 can also be used, but with the duration shortened to 50 hr. In this case the resulting value and character of the wear, as seen from Fig. 29, are completely comparable to those of Conditions No. 6 with a 100-hr test program.

3. With the combined test conditions, No. 7, for combined forms of wear, all the specific individual features of the test conditions for corrosion and abrasive wear are lost. Accordingly, the functionality under which each of these is expressed is destroyed and, consequently, it becomes difficult to evaluate them quantitatively or qualitatively. Thus, Conditions Nos. 5 and 6 are recommended. Five to seven engines of each of the models GAZ-51, GAZ-21, and GAZ-53 were tested under each of these sets of conditions. The results of these tests are reported in Table 17, along with wear after lengthy service and after testing according to the conditions of GOST 491 - 55, given for comparison. From an analysis of the test results it was determined that the abrasive wear of cylinders is comparable with wear after a vehicle service mileage, for UAZ-450, of about 70 - 80×10^3 km, for GAZ-51 on the average 55 - 65×10^3 km, for "Volga" automobiles 110 - 120×10^3 km, and for GAZ-53 from 80 - 100×10^3 km.

Since the tested engine models differ in a number of design and engineering properties, it may be considered established that the recommended sets of test conditions for evaluating abrasion resistance of the main parts of the cylinder-piston group and the crankshaft-connecting rod mechanism can be applied to different models of automotive engines. From mathematical treatment of the results of test stand and road tests, proportionality coefficients were obtained between road and test stand conditions, in hours and in kilometers, and the number of engines was found which must be tested in order to objectively analyze the applicability of a given measure aimed at increasing engine life. In particular, it was found that for flathead GAZ engines reliable results can be obtained from testing of five engines, and for overhead valve models with wet cylinder sleeves 5 to 7 engines must be tested.

The number of engines needed to evaluate the effectiveness of measures with the same precision under test stand tests is 2.7 to 3.2 times less for UAZ-450 and GAZ-69 models; 3.5 times less for GAZ-52, 2.0 to 4.5 times for GAZ-21, and 2.3 to 3.0 times for GAZ-53. The length of test stand tests to evaluate the effectiveness of various measures is 21 to 26 times shorter than that needed for evaluation under service conditions.

The average savings on a single engine model for accelerated test stand testing as against service testing is $27\text{-}45 \times 10^3$ rubles, depending on the model.

Thus, the method which was developed of accelerated test stand testing of engines for abrasive wear and tear is much more practical in the solution of problems of engine life, and is relatively simple and economical. At present the finishing touches are being applied in the direction of assuring stability in the metered feeding of dust to the engine cylinders. For this purpose, new improved automatically controlled dust dosing feeders were developed at the GAZ in conjunction with the Gorki Design and Engineering Institute.

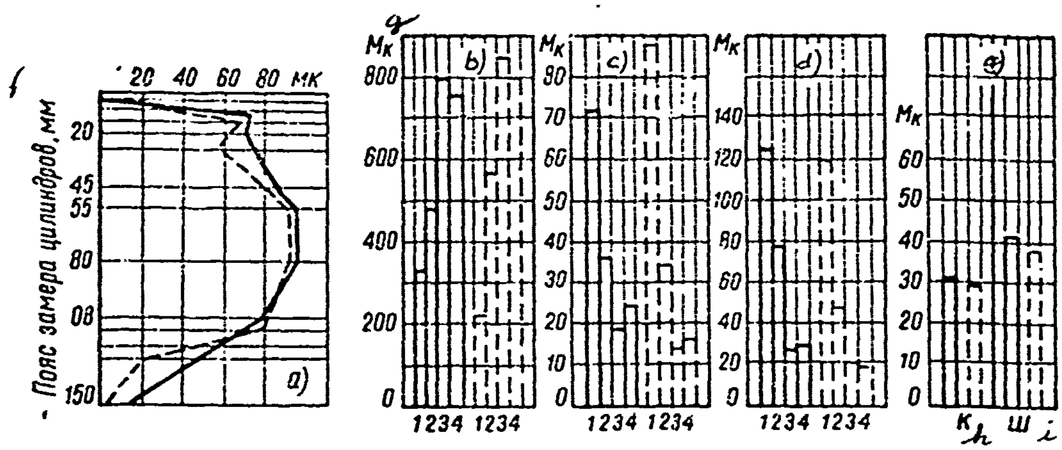


Fig 29. Average Wear of Parts of UAZ-450 Engines as Functions of Test Time and Dustiness: a -- cylinder wear; b -- wear of piston rings, with respect to radial thickness; c -- wear of rings with respect to height; d -- wear of grooves; e -- wear of main journals and crankpins;
—— 100-hr program of Conditions No. 6 [of Table 15]; ---- = 50-hr program of Conditions No. 5; 1,2,3,4, [in Graphs b - e] = number of the ring;

Key: f = Zone of measurement of cylinder, mm; g = microns; h = Main journals; i = Crankpins.

It should be remarked that the recommended versions of sets of test conditions for engine life do not exhaust all possibilities in this direction. Thus, they do not include methods of evaluating wear resistance of the parts of the valve-camshaft mechanism, and especially the heat resistance of pistons and valves. The insufficient heat resistance of valve heads is a consequence of the tendency to increase the power and speed of contemporary automotive engenes, which necessarily involves an increase of the compression ratio and the use of high octane gasoline. The use of high-ethyl gasolines with up to 2.5% or more tetraethyl lead content has a particular effect on burn-through of the valves, both as a result of scale deposition, which lowers heat transfer, and as a consequence

Table 17.

Таблица 17

Изнашивание детали a			Цилиндры двигателя b	Верхнее кольцо c		Верхняя поршневая канавка f	Шейки коленчатого вала g	
				по радиальной толщине d	по высоте e		коренные h	шатунные i
УАЗ-450 j	Режим 6 l	Средний износ m	90—100	340—360	65—75	100—110	25—35	45—55
		Предельный износ n	100—130	380—400	80—85	110—115	50—55	55—60
	Пробег 70—80 тыс. км o		100—150	250—300	100—200	50—100	65—75	70—90
ГАЗ-51 k	Режим 6	Средний износ	100—105	550—600	120—130	175—185	20—30	35—40
		Предельный износ	120—135	635—650	130—140	200—210	40—45	60—70
	Пробег 50—60 тыс. км		95—105	—	—	—	45—55	60—70
ГАЗ-21	Режим 6	Средний износ	170—180	300—310	65—75	135—145	20—25	5—6
		Предельный износ	195—220	370—390	75—85	150—160	25—30	10—15
	Пробег 120—130 тыс. км		200—220	120—140	120—130	75—80	50—60 25—30	тыс. км p 10—15
ГАЗ-53	Режим 6	Средний износ	65—70	200—210	50—60	135—140	8—10	8—10
		Предельный износ	85—90	250—260	65—70	145—150	10—15	10—15
	Пробег		—	80—85	40—45	45—50	50—60 25—35	тыс. км 15—20

Key: a = Wear and tear of parts; b = Cylinders; c = Upper ring; d = with respect to radial thickness; e = with respect to height; f = Upper piston groove; g = Crankshaft journals; h = Main; i = Connecting rod; j = UAZ-450; k = GAZ-51; l = Conditions No. 6; m = Ave. wear; n = Maximum wear; o = service mileage of 70 - 80x10^3 km; p = 50-60 x10^3 km.

of corrosion caused by lead compounds. A special method was developed in the engine laboratory of the motor vehicle plant for evaluating the heat resistance of valves and their resistance against burn-through. It is based on the use of high-ethyl gasolines for testing, variation of mixture richness over the entire range up to a value of the coefficient of excess air, α, of 0.5 - 0.6, and operation of the engine under conditions of maximum power output. The condition of the valves is judged from the size of the gap between the valve and the rocker arm in a cold engine and from cylinder compression in a hot engine.

Decrease of the gap and compression loss occur as a result of bending of the valve head and lengthening of the valve stem. In tests of engines by this method burn-through of the valve heads set in within 130 - 200 hrs of testing, and the heat resistance of a given valve was judged according to this standard limit for ordinary valves. The performance capability of valve seats is evaluated by this same method.

Application of Methods of Accelerated Test Stand Testing

The application of methods of accelerated test stand testing for abrasive wear and tear of parts is based on the plotting of limiting wear diagrams, or "wear fields" for each concrete automotive engine model. These "fields" take into account the scatter and the character of the wear which arises in the process of test stand testing. The effectiveness of a given measure is determined by comparing the wear lines of parts of experimental engines with the maximum wear of standard engines of the same model, plotting the experimental lines according to the average results of measurement of parts of engines tested by the accelerated method. "Wear fields" are given in Fig. 30 for cylinders of over 60 UAZ-450, GAZ-51, GAZ-21, and GAZ-53 engines tested according to the 50-hr and 100-hr accelerated method of Conditions No. 6. The location of a wear line for cylinders of experimental engines to the left of the crosshatched "wear field" of the diagram indicates that the proposal for lowering wear which is being tested is clearly effective. Displacement of this line towards the right side of the crosshatched zone or beyond its limits is evidence that the given measure is ineffective. Evaluation of the wear resistance of the remaining parts is analogous.

In the process of testing engines by the 100-hr version of Conditions No. 6 or the 50-hr Conditions No. 5, certain indices change, including those of oil burning, gas blow-by, and effective power, as a result of wear of the parts friction surfaces. In Fig. 31 the data on the variation of torque and effective power are given, with their scatter being represented by the crosshatched zone.

With the aim of testing the proposed method of accelerated test stand tests by the 100-hr program of Conditions No. 6, UAZ-450 engines, the blocks of which having been manufactured without dry Nirezist anticorrosion inserts, were tested for abrasive wear and tear. As would be expected, the wear of the cylinders without inserts was substantially higher than that of standard engines. However, in tests of the engines for corrosion wear under Conditions No. 4 the wear of the engines with inserts and without turned out to be practically the same. On the basis of this it was concluded that the prevalent effect of Nirezist inserts

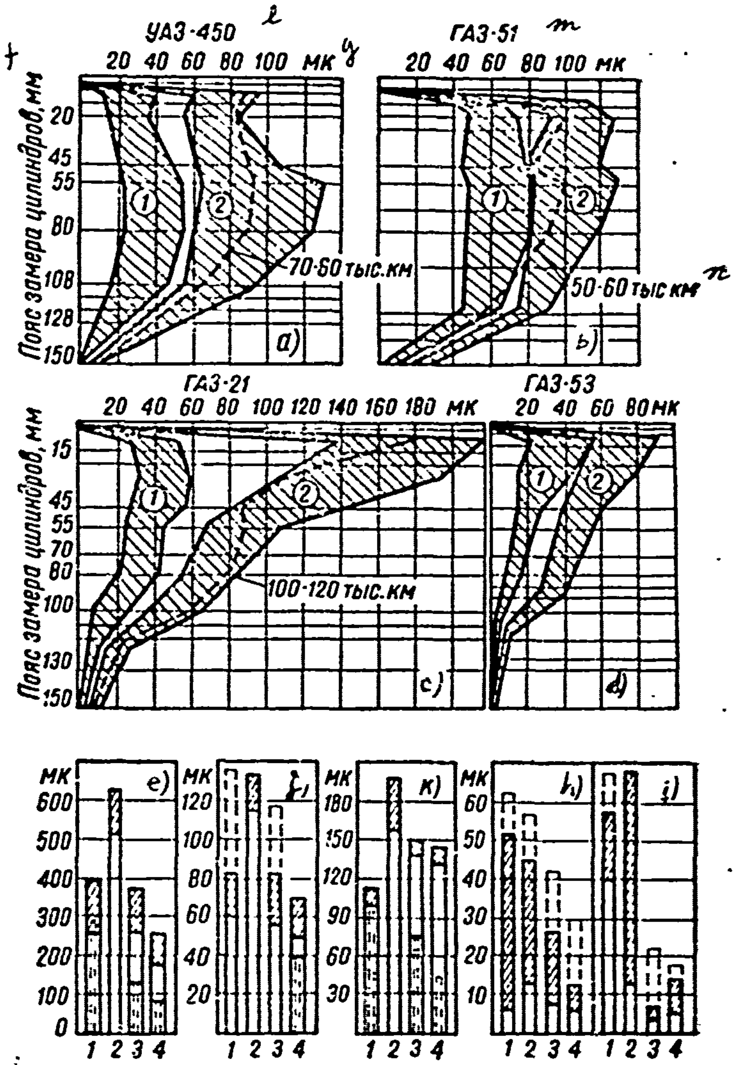


Fig. 30. Limiting Wear Values of Parts of Standard Engines Under Accelerated Testing:
a,b,c,d, -- limiting values of cylinder wear; 1 -- in 50-hr program of Conditions No. 6; 2 -- in 100-hr program of Conditions No. 6; e -- wear of first piston rings, with respect to radial thickness; f,g,h,i -- same as in Fig 29; j -- wear of first piston rings with respect to height; k -- wear of first piston grooves; ℓ -- UAZ-450; m -- GAZ-51; n -- 50 - 60x10^3 km,
Bar 1 -- UAZ-450; Bar 2 --GAZ-51; Bar 3 -- GAZ-21; Bar 4 -- GAZ-53;
---- Service wear (UAZ-450, 70 - 80x10^3 km; GAZ-5i, 45 - 55x10^3 km; GAZ-21 and GAZ-53, 50 - 60x10^3 km).

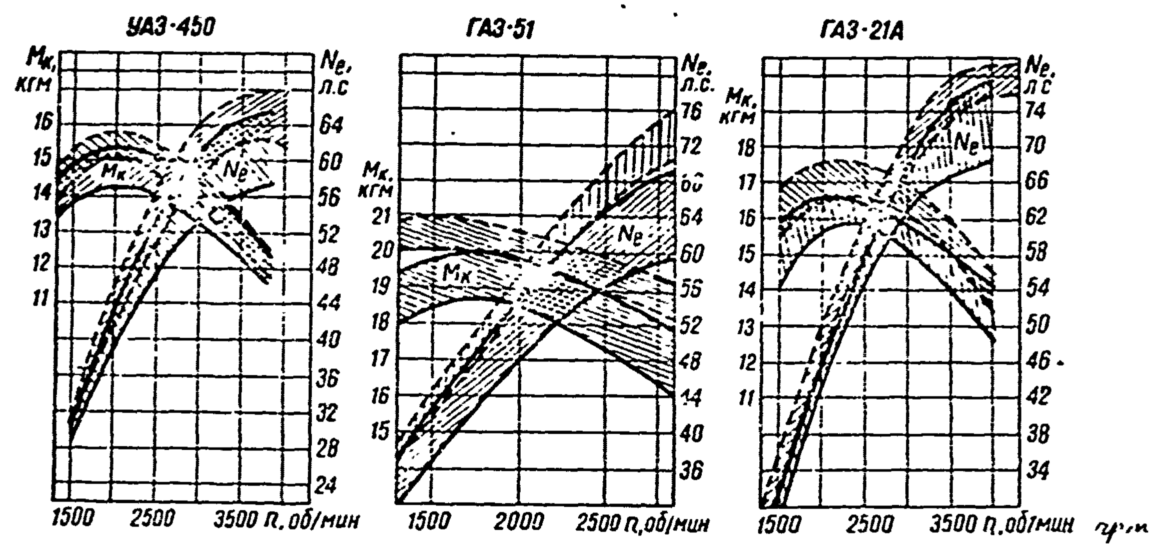


Fig. 31. Change in Torque M_k (kgf-m) and Effective Power Ne (hp) after 100-hr Test Stand Testing:
---- according to plant Engineering Specifications ("TU");
____ by accelerated method.

is on abrasive wear. With respect to anticorrosion properties of Nirezist, it was assumed that Conditions No. 4 are inadequate.

The use of the method which was developed made it possible to evaluate such measures as dense chroming of the piston rings in place of the existing porous chroming; alterations of the phosphorus and copper content in the cast-iron of the engine block; the use of tungsten and titanium alloy piston rings; the use of experimental cylinder sleeves made of tubular stock manufactured by the method of continuous casting; comparison of the wear resistance of cylinders machined by abrasive and diamond bars; and the effect of final machining of crankshaft journals on their wear resistance (Fig. 32). All of the measures which were designed to increase life of the cylinder-piston group were subjected to a 50-hr test program according to Conditions No. 6. Dense chroming was tested because of a number of advantages of this process over porous chroming of piston rings. It excludes the possibility of chipping of chrome particles and embedding of material into the surfaces of the fitted parts, it has a low coefficient of friction between the coating and its matching surface, and the technology of applying the coating is not complex. Accordingly, savings of 30% are achieved in the chroming. Tests of 5 engine types confirmed that the wear of the experimental rings was twice as low as that of porous-chromed rings, and cylinder wear was close to the minimum limit of wear of cylinders of UAZ-450 engines.

The effect of the content of phosphorus in the cast iron of the engine block upon cylinder wear was tested with GAZ-51 engines. The lowering of the percent phosphorus content had the aim of reducing flaws in the casting of engine blocks.

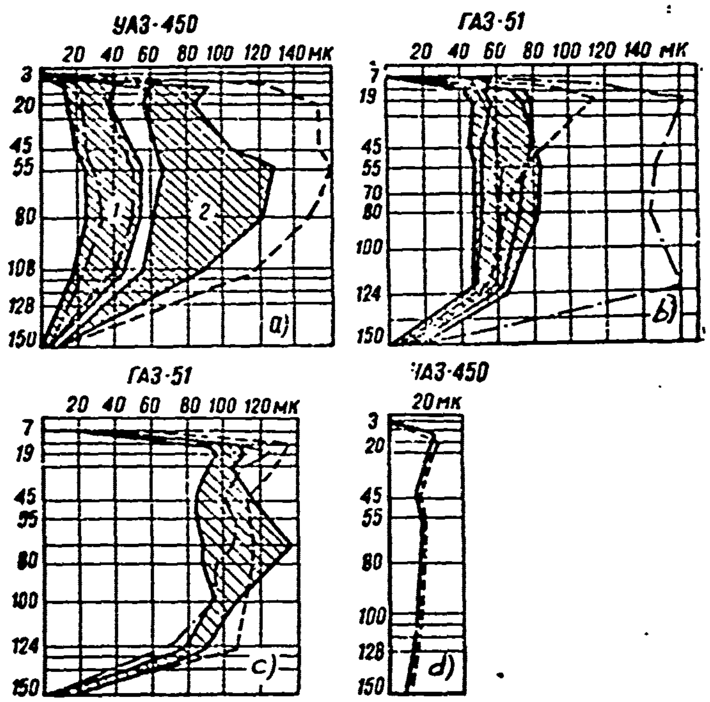


Fig. 32. Evaluation of Techniques, Using the Accelerated Test Stand Testing Method:

[wear-field hatching symbol] -- "wear fields"

a -- Cylinder wear in UAZ-450 engines;
1 -- in 50-hr program of Conditions No. 6;
2 -- in 100-hr program of Conditions No. 6; -··- [sic] upper piston ring, with dense chrome over knurling; -·- cast iron block with 0.20% copper; ---- cylinders without austenitic inserts;
b -- Cylinder wear in GAZ-51 engines, in 50-hr program of Conditions No. 6; -x- cast iron block with 0.25% phosphorus content; -//- cast iron block with 0.12% phosphorus content; ---- piston rings of titanium and tungsten alloys; --- cylinders machined with abrasive bars; -··- engine following major overhaul.
c -- Cylinder wear in GAZ-51 engines, in 50-hr program of Conditions No. 5; ---- metalloceramic piston rings; -·- engine following major overhaul.
d -- Cylinder wear in UAZ-450 engines, under Conditions No. 4; ---- cylinder wear of standard engine; ____ wear of cylinders without austenitic inserts.

It was shown in tests that lowering the percent of phosphorus in the cast iron causes increased cylinder wear. Adding copper to the cast iron of the cylinder block of UAZ-450 engines with the aim of decreasing flaws in the castings also caused increased cylinder wear. In tests of lightweight piston rings on 7 GAZ-51 engines it was found that rings made of tungsten and titanium alloy have increased wear resistance and lower loss of elasticity. In the absence of scoring, cylinder wear with the alloy rings is not higher than wear with standard rings, but the possibility of scoring of cylinders of GAZ-51 engines is higher with the alloy rings.

In addition, piston grooves paired with alloy rings wear more than with standard rings.

In studies of the comparative effect on cylinder wear of honing with abrasive bars and with synthetic diamond bars, under the latter method of machining the cylinders were found to have substantially higher wear resistance. This is seen from the fact that the wear curve of the cylinders machined with the abrasive bars is located to the left of center of the "wear fields", which itself was plotted from wear data of cylinders honed with synthetic diamond bars.[8] Measures intended to increase the life of crankshafts were tested by the 100-hr test program of Conditions No. 6, on GAZ-51 engines. It was discovered that the method of final machining of the part affects its wear resistance. By changing the method of final machining of the main crankshaft journals, their wear resistance can be increased by from 7 - 62%. In this respect, microfinish treatment looks very promising for the removal of the defect layer which forms when they are polished.

A comparative evaluation was also made of the life times of engines which had been overhauled at the vehicle overhaul plant which operates under the auspices of the Gorki Motor Vehicle Plant; the evaluation method proposed above was used. It was noted earlier that the statistics indicate low life time of engines after major overhaul: they last for 25 - 30×10^3 vehicle km. This short engine life is explained by the weak technical basis of vehicle repair enterprises, the low quality of the spare parts, the deficient degree of sophistication of the overhaul processes, and the lack of a common and well-controlled technology of major overhaul of automotive engines. Thus, as a result of inspection and micrometry of overhauled GAZ-51 engines which had been sent to the laboratory, numerous deviations of the geometrical parameters and assembly standards from the specifications established for the manufacture of new engines at the Gorki Motor Vehicle Plant were observed. In particular, the following deviations were noted: displacement of cylinder axes relative to the pillow blocks of the crankshaft by 0.36 mm in excess of the tolerance, coaxial nonalignment of the main crankshaft pillow blocks up to 0.1 mm (with the tolerance being 0.04 mm), curvature of the connecting rods up to 1.4 mm in excess of the tolerance, exceptionally tight-fitting pistons, etc. Tests of GAZ-51 engines which had undergone major overhaul, using a 100-hr program under Conditions No. 6, showed that as soon as 50 hours of operation had passed on the test stand they were unsuitable for further testing. Cylinder wear in these engines exceeded

[8] [Translator's note: The author apparently has his facts reversed here.]

cylinder wear of new engines manufactured at the Gorki Motor Vehicle Plant by 2.5 times, and oil burning and gas blow-by was the same as in engines which needed major overhauls. In addition, the wear of the main crankshaft journals and crankpins was unacceptably large. This was the result of large initial macrodeformations, and cracks and lowered hardness in the surfacing layer applied when the crankshafts were restored at the vehicle overhaul plant. From the data of these tests measures were recommended to the vehicle repair plant collective to provide increased engine life of engines after major overhaul. These involved improvements in the technology of the overhaul and assembly of subunits: machining cylinders and control of their geometric parameters, proper fitting of pistons, testing of macroscopic-scale errors in crankshaft journals, etc. Following the adoption of these and other measure, engines which had undergone major overhaul were tested under laboratory conditions at the Gorki Motor Vehicle Plant under the 50-hr program of Conditions No. 5.

The tests showed that adoption of the series of recommendations resulted in a nearly twofold lowering of cylinder wear. A certain amount of increased wear in the upper zone of cylinders in engines which had undergone overhaul in comparison with standard engines was attributable to the installation of tin-plated upper compression piston rings in the major overhaul, whereas the rings installed in new engines are coated with porous chrome. At present at the Central Research Laboratory for Engines at the Gorki Motor Vehicle Plant the effectiveness of a number of new measures developed to increase product life is being evaluated using the recommended method of accelerated engine testing. At the same time, equipment is being built at the Laboratory for natural testing of cylinders, piston rings, and other parts. These will enable preliminary evaluation of the expediency of adopting new measures, in less time and with less expense than test stand tests. In testing heat resistance of exhaust valves and seats conditions of maximum loading are used, with engines using ethyl gasoline, as described in the previous section. The criterion of heat resistance in these tests is the length of the test of the engine in hours until burn-through of the parts in question begins.

In recent years tests have been carried out on exhaust valves with aluminized heads, valves made of various types of heat-resistant steel, valves with heads surfaced with temperature-resistant alloys, filled with sodium, and others.

Currently evaluations are being conducted according to the method of this section on the heat resistance of exhaust valves made of EP-303 nitrogen-containing steel, and valves alloyed with silicon, niobium, and sulfur. Along with this the performance capability of seats made of chrome cast iron is being tested, with the aim of adopting a single alloy for the valve seats of GAZ and ZMZ engines. The goal of the exploratory work in this direction is to find an alloy which has good machinability and performs very well both in cast iron blocks and in cylinder heads made of aluminum alloys.

Thus, the use of accelerated engine testing opens wide possibilities for practical testing of the effectiveness of various measures for increasing engine life.

It must be assumed that further development of the methods of accelerated testing will substantially enlarge the arsenal of design and engineering methods of increasing the quality of the products leaving our plant, and in particular automotive engines. The invention, analysis , and application of such methods is one of the problems which the KANARSPI method can solve.

Conclusions

In this book research in the area of increasing the life time of engines from the Gorki Motor Vehicle Plant and the Zavolzhsk Motor Plant is reported on and the experience of introducing a number of recommendations which were developed is described.

Many of these measures can be used also in other motor vehicle enterprises and machinery manufacturing plants, and some have even found recognition and are being employed in other branches of industry. Still, the sources of means of further increasing the service life of machines, including engines, are far from being exhausted, some of the possibilities have either not been discovered or are insufficiently understood, and other recommendations have not been applied under production conditions. The above demonstrates the need to set down the different situations in distinct and concrete form and to formulate the sequence of problems in the area of increasing engine life. These current situations and problems are presented below.

1. The unevenness of the quality of parts manufacture leads to substantial variation of the performance and economic indices of engines and of the wear resistance of subassemblies and fitted assemblies in them. The proper organization of research efforts and the combined introduction of scientific and engineering as well as organizational measures contribute to increasing the stability of the quality of parts and engines.

2. It is very practical to differentiate mechanical, molecular mechanical, and corrosion-mechanical forms of wear and tear with regard to present-day machines, including automotive engines.

3. The life time of contemporary automotive engines is definitely too short. This is particularly the case in vehicle service under conditions of appreciable dust in the air. The unacceptably low life of engines after major overhaul deserves particular attention. This state of affairs can be corrected by putting automotive overhaul plants under the assistance and patronage of large automotive enterprises.

4. One of the most important research problems is the creation of new methods of evaluating wear, engine life, and the technological condition of engines, as well as the improvement of existing methods.

5. Despite the large number of studies of operating conditions and wear of parts which have been carried out, many points in this area are still in

controversy, which makes the job of developing means of increasing engine life more difficult. In this regard it is desirable to continue research on heat straining of engines and to devise theoretically based recommendations for improving heat transfer in engines, as well as to intensify research on the deformation of parts and into generalizations of the character and dynamics of parts wear.

6. Design, engineering, and operational means of increasing engine life are practically inexhaustible, but taking advantage of these possibilities is often limited by the imperfect state of the production processes and the technology of equipment and tools. Thus, at present, artificial "aging" of cylinder blocks has not been adopted for all engine models, Invar inserts for lowering piston deformation are not being used, the technology of hard chroming of piston rings has not been developed, etc.

7. Methods of accelerated testing with the use of quartz dust, and a method of evaluating the heat resistance of valves were designed, developed, and tested for use in the practical evaluation of the effectiveness of other methods developed to increase engine life. The need should also be recognized to develop methods of accelerated natural testing of parts and subassemblies, to make the solution of problems connected with engine life still more workable.

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